AD-A159 447 WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS (.. (U) ROYAL STATISTICAL SOCIETY LONDON (ENGLAND) 1983 R/D-4176-MA DAJA45-83-M-0225 1/1

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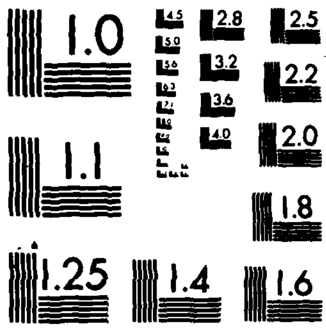

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FASRAFA

1983

Summary of Research Interests of Participants

Arranged in alphabetical order by participants surnames

[Note: Each participant was asked to provide for general distribution a summary of his research activities as he felt appropriate - anything between 200 and 2000 words was suggested. These are reproduced here as submitted. The vague nature of the request for summaries was deliberate as this Workshop has as one of its functions that of being a 'pilot' for future Statistical Workshops that it is hoped will find a permanent base in Edinburgh. Participants are invited to express a view on what type of summary they consider most useful. These views may be given to me or to Peter Fisk who will be playing a key role in the organization of the next Workshop.]

DAJA 45-83-M-0225

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WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

D J Bartholomew: Current Interests

On the theoretical side I have been working on the foundations of factor analysis. This work was described in three post-graduate lectures in London in 1982. A written paper was circulated subsequently and a shortened version is being submitted for publication. This work was stimulated by my interest in factor analysis for categorical data. The aim was to find a satisfying theoretical framework within which existing models could be accommodated and new ones developed. The key idea is to regard the problem as one of data reduction (strictly, reducing the dimensionality of the data) to be achieved using the notion of Bayesian sufficiency. The inevitable arbitrariness involved can be reduced, but not eliminated, by introducing invariance and symmetry considerations. Standard (normal) factor analysis fits into this scheme as do some methods which have been proposed for analysing binary data.

On the practical side I have acquired several large data sets concerned with educational testing, graduate selection and staff appraisal. Most of the variables are categorical (usually ordered). With the help of a student I am in the course of evaluating various methods for fitting the latent variable models to such data. This includes an evaluation of the Rasch model used in educational testing. I am particularly interested in the problems posed by ordered categorical data where recent work on regression models with ordinal dependent variables seems to be relevant.

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4) Scaling binary data J ROY STATIST SOC B (1983 or 4) to appear.

5) Latent variable models: some recent developments. A correspondent paper submitted to INT STATIST REV.

6) Foundations of factor analysis. submitted for publication.

M L BARTLETT

THE LINEAR STRUCTURAL RELATION APPLIED TO CALIBRATION OF BIOCHEMICAL ASSAYS.

There is a class of measurement systems,especially biochemical assays and including immunoassays and receptor assays,in which the system is calibrated with a set of calibrators before use on a batch of test specimens. The calibrators and test specimens potentially have differences of behaviour,which leads to inaccuracies('method bias') To assess a method then ,the new method is compared with a reference method .This is called a method comparison study.A central distinctive feature of this in biochemical assays is that both methods have non-negligible random errors.Specifically the objective of a method comparison study is to assess the inaccuracy and imprecision of the new method.The equations describing the comparison comprise a structural relation,and under further restrictions that the calibration curves of both methods can be linearised by the same transformation, the linear structural relation is obtained.Relating the parameters of the L.S.R. to the biases of the new method is not trivial and involves the calibration process. Under calibration homoscedasticity,independence,and normality the L.S.R.errors will be heteroscedastic and non-normal. The usual way of conducting a method comparison study -a single calibration before a batch of test specimens,leads to correlations in the errors .

The common way of analysing a method comparison study is to use simple linear regression on the final measurements with the new method taking the reference method as exact(Westgard and Hunt 1973).There are also methods of multiple comparisons of methods where none is considered the reference method - these are not considered here.The simple linear regression analysis ignores the effect of recalibration and reference method errors,and so leads to biases in estimates of method bias .These reference errors can of course be reduced by replication,but this is not neccessarily done ,or even efficient. Method comparison studies are also assessed by use of the simple correllation coefficient at times.A critical review of simple methods of analysis ,not including use of the L.S.R. has recently been made (Alton 1983),who proposes his own method of analysis,not based on the L.S.R.,which again has limitations.An analysis of the comparison has been proposed by Lloyd(1978) using estimates from the Normal L.S.R.but again there are inadequacies of assumptions and analysis in his treatment.Barnett(1969) has used a L.S.R. to compare two measuring instruments,but in that example there is no recalibration and his simple error structure seems to be reasonable.

When a particular measurement method can be nominated as a reference method,it is reasonable that its error variance will be known.If one then approximates the true error structure by an i.i.d. Normal error the relevant estimates for method bias are those with one error variance known and are given by

Kendall and Stuart(1979).Their asymptotic variances and biases are given by Robertson(1974).

Our present effort is to determine how good such a simple estimator from the normal L.S.R. ,given our approximations and to find a description of the conditions under which estimation fails .Simulation studies are being made of the full situation taking into account the calibration process.They have validated our description of the situation and shown estimation can be good,and that the Robertson expressions for the asymptotic variances are accurate.However under some conditions the estimation of the method bias can be about 50% biased,and these biases are not in accord with predictions of Robertson(1974).We are trying to unravel the source of this bias.

All the above work is for the without replication case.It needs to be repeated for the perhaps more useful with replication case.

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SUMMARY OF CURRENT RESEARCH IN THE AREA OF FUNCTIONAL AND STRUCTURAL RELATIONSHIPS

N.N. CHAN

Current research in the area undertaken by N.N. Chan can be summarized as follows:

(1) Provided a solution to the estimation problem (which has long been outstanding) of a linear structural relationship with unknown error variances. See Ref. (a) below.

(2) Considered the generalized least squares estimation of a multivariate linear functional relationship (Ref. (b)).

(3) Solved the estimation problem of a multivariate linear functional relationship, in particular, the estimation of its error covariance matrix (joint work with T.K. Mak, Ref. (c)).

(4) Considered the linear functional relationship model with correlated and heterogeneous errors (with T.K. Mak, Ref. (d)).

(5) To investigate problems relating to linear and nonlinear functional relationships models (Refs. (e) & (f)).

(6) To review relations between functional and structural models and those of factor analysis (Refs. (g) & (h)).

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(b) Estimating linear functional relationships. In Recent Developments in Statistical Inference and Data Analysis (1980), pp.29-34. Amsterdam: North-Holland.

(c) Estimation of multivariate linear functional relationships. Biometrika 70 (1983), pp. , (with T.K. Mak).

(d) Estimation of a linear transformation with correlated errors. In Recent Developments in Statistical Theory and Data Analysis, Pacific Area Statistical Conference (1982), pp.85-88. Tokyo, (with T.K. Mak).

(e) On circular functional relationships. J.R. Statist. Soc. B, 27 (1965), pp.45-56.

(f) A criterion for the consistency of parameter estimators of functional relationships. Conference Volume, 42nd Session of International Statistical Institute (1979), pp.91-94.

(g) Stochastic approximation for linear structural relationship. Bulletin of the International Statistical Institute, Vol.47, Part IV (1977), pp.108-111, (with T.S. Lau).

(h) On an unbiased predictor in factor analysis. Biometrika 64 (1977), pp.642-644.

Workshop on FASRAFA: Dundee 1983

Some Research Interests: J.B. Copas

1. A major research effort in recent years has been the study of shrinkage estimates in linear models, see Copas (1983a). In this paper, a constructive motivation for Stein estimations is given based on statistical properties of the predictor $\hat{y} = \hat{\underset{\sim}{\beta}}^T \underset{\sim}{x}$ as $\underset{\sim}{x}$ varies over a population of future values. Using this argument it is seen that the best predictor of the true response y is not $\hat{y}$ but $K\hat{y}$ where K is a function of both $\underset{\sim}{\beta}$ and $\hat{\underset{\sim}{\beta}}$ which has expectation strictly less than one. An unbiased estimator of K leads to a shrinkage factor mathematically equivalent to the James-Stein formulation for the normal mean. The prediction mean squared error of $\hat{K}\hat{y}$ is uniformly lower than that of $\hat{y}$ if the number of x_i's exceeds 2. Shrinking maximum likelihood is natural when it is prediction that is the objective, but nothing is said about other objectives such as estimation or testing.

It is of interest to see the implication of this work to linear structural and functional relationships. Prediction arguments do not of course apply, as they imply conditioning on $\underset{\sim}{x}$ rather than estimating the underlying relationship between $\underset{\sim}{x}$ and y. However, shrinkage estimates may still be superior to maximum likelihood in certain contexts. The possibilities are indicated by the following heuristic argument.

Consider the bivariate Structural Relationship with λ known.

$$X \sim N(\mu, \sigma_x^2), \qquad x_i \sim N(X_i, \sigma^2)$$

$$Y = \alpha + \beta X, \qquad y_i \sim N(Y_i, \lambda\sigma^2); \qquad i = 1,2,\ldots,n.$$

Then the usual ML estimate of β say $\hat{\beta}$ (depends on λ), has asymptotic mean β and asymptotic variance

$$V_\lambda = \frac{\sigma^2((\lambda+\beta^2)\sigma_x^2 + \lambda\sigma^2)}{n\ \sigma_x^4} .$$

(This formula needs careful interpretation as the moments of $\hat{\beta}$ do not exist

for finite n). The asymptotic mean squared error of $K\hat{\beta}$ is therefore $(1-K)^2\beta^2+V_\lambda K^2$. This is least when

$$K_\lambda = \frac{1}{(1+\frac{\lambda\sigma^2}{n\beta^2\sigma_x^2})(1+\frac{\sigma^2}{n\sigma_x^2})}$$

$$= K_x K_y,$$

where K_x is the optimum shrinkage for the model with the error in x only, and K_y for the error in y only. For a given correlation between x and y, the value of K_λ depends rather little on λ, so that the shrinkage for the structural relationship model is similar to that for the simple regression model with the same overall correlation.

This argument is of no immediate practical value since the K's are treated as constants and not sample estimates. In the ordinary regression case the number of independent variables has to exceed 2 before the extra variability in the estimation of K is compensated for by the improvement inherent in shrinking. Presumably it is the multivariate version of the structural model which will be needed. Can the theory be worked out? What is the effect of errors in the x's on the other aspects of regression discussed in the cited paper?

2. Another research interest is the use of binary models in prediction and discrimination. A probit model for example is

$$P(S|\underset{\sim}{x}) = \Phi(\alpha+\underset{\sim}{\beta}^T\underset{\sim}{x}).$$

If the $\underset{\sim}{x}$'s are measured with normally distributed errors giving observed readings $\underset{\sim}{z}$, then $P(S|\underset{\sim}{z})$ is still a probit regression but with different α and $\underset{\sim}{\beta}$, as in Copas (1983b). This paper shows how the bias due to errors in the x's can be corrected - it leads to an increase in slope estimate akin to raising the least squares slope of y on x in simple regression towards the regression of x on y. But the errors in the x's are assumed known - presumably the model

is unidentifiable otherwise. In practice some replicated observations may be available at some or all of the different true values of x.

3. Practical Applications

A number of interesting practical problems lead to models of the FASRAFA type. Examples are:-

a) Split sample analysis in chemical assays

A blood sample from each of n patients is split into two parts, one giving observation x_i by method A and the other giving observation y_i by method B. We assume a structural relationship

$$E(y_i) = \alpha + \beta E(x_i),$$

with various possible assumptions about the errors e.g. a constant coefficient of variation. Additional data on replication may be available in which both halves are measured by the same method. It is of interest to test whether $\alpha = 0$, $\beta = 1$ and the fitted error structure accords with whatever data is available on replication. A simple example is in Brooks, Copas and Oliver (1982). For radioimmunoassay data, a calibration procedure is involved which introduces additional complications (Michael Bartlett is working on more detailed models).

b) Coal/oil flow ratios

A coal/oil mixture in stream 1 is intercepted by a sieve which divides the stream into two parts, stream 2 being the intercepted material and stream 3 being the residue which passes through the sieve. The fraction of the total mixture retained by the sieve is β, which it is required to estimate. Independent measurements (subject to error) are made on each of

y_i = fraction of coal in stream i

x_{ij} = fraction of the coal in stream i which is of particle size j.

Then by conservation of coal we have

$$y_1 = \beta y_2 + (1-\beta)y_3$$

$$x_{1j}y_1 = \beta x_{2j}y_2 + (1-\beta)x_{3j}y_3 \qquad j = 1,\ldots,k.$$

Various assumptions are possible about the error variances.

c) Blood tests for diagnosis of leukeumia

The disease state of patient i ($i = 1,2,\ldots,n$) is indexed by p_i, the proportion of abnormal cells in the patient's blood. A test consists of a series of k measurements x_{ij}, $j = 1,2,\ldots,k$, these being the observed proportion of cells killed when a blood sample is added to a colchicine solution of concentration j. Let ξ_j and η_j be the true proportion of abnormal and normal cells killed by concentration j respectively. Then

$$x_{ij} = p_i\xi_j + (1-p_i)\eta_j + \text{error}.$$

Normal patients have $p_i = 0$ and patients known to be in a particular leukeumic state have $p_i = 1$. To allow for errors in diagnosis, assume

$$p_i \sim N(\mu_i, \tau_i^2).$$

For one group of patients thought to be normal, μ_i and τ_i could be suitable small positive constants. For patients thought to be in the leukeumic state, μ_i could be near 1 but with the same τ_i. For a third group of unclassified patients we may take $\tau_i = \infty$. The problem is to estimate the ξ's, η's and p's. Again various assumptions on the error structure are possible.

d) Consumer testing using a panel of respondents

In a consumer testing trial, housewife i gives a response x_{ijk} using a rating scale for the jth attribute on the kth product. The jth attribute on the kth product has a true value ξ_{jk}, but each housewife has a different perception of the rating scale and a different error variance so that

$$x_{ijk} = \alpha_i + \beta_i\xi_{jk} + \varepsilon_{ijk}$$

with $\mathrm{Var}(\varepsilon_{ijk}) = \sigma_i^2$. Some replication is available in that a standard product may form more than one value of k. It is required to test for product differences and to estimate σ_i^2 so that a panel of respondents who show good consistancy of scores can be selected for further trials.

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Copas, J.B. (1983b) "Plotting p against x", Appl. Statist., to appear.

CURRENT RESEARCH INTERESTS

(a) Survey methods

- (i) Controlled Selection
- (ii) Statistical Matching
- (iii) Bootstrap techniques in survey analysis

(b) Statistical Computation

- (i) Rank order sampling
- (ii) Bootstrap techniques in complex problems
- (iii) Design of Monte Carlo studies

P.R. FISK

4 July 1983

RESEARCH INTERESTS

Wayne A. Fuller
Iowa State University

I am currently working on extensions of the functional and structural model. Under consideration are models with measurement error that is not normal, models with heterogeneous error variances, models with error variance functionally related to the true values, multinomial response models and nonlinear models. My recent research is described by the following titles and abstracts.

(with Y. Amemiya) Estimation for the multivariate errors-in-variables model with estimated covariance matrix.

The errors-in-variables model with multiple linear relationships is considered. It is assumed that an estimator of the covariance matrix of the measurement error is available. The maximum likelihood estimators are derived for the model with normally distributed unobservable true values. The limiting behavior of the estimators is investigated for a wide class of assumptions including the case with fixed true values.

(with G. D. Booth) The errors-in-variables model with nonconstant covariance matrices.

The large sample properties of the maximum likelihood estimator are presented for the linear functional model in which the covariance matrix of the errors varies from observation to observation. An estimator that can be used to initiate calculations for the maximum likelihood estimator is presented.

(with T. C. Chua) A model for multinomial response error.

A model for the response error associated with reported categorical data is developed. The model is used to construct estimators for the interior cells of a two-way table with marginals subject to independent response error. The estimation procedure is applied to the two-month table of employment status obtained from the U.S. Current Population Survey.

(with P. F. Dahm) Generalized least squares estimation of the functional multivariate linear errors-in-variables model.

Estimators of the parameters of the functional multivariate linear errors-in-variables model are obtained by the application of generalized least squares to the sample matrix of mean squares and products. The generalized least squares estimators are shown to be consistent and asymptotically multivariate normal. Relationships between generalized least squares estimation of the functional model and of the structural model are demonstrated. It is shown that estimators constructed under the assumption of normal x are appropriate for fixed x.

(with Y. Amemiya and S. G. Pantula) The covariance matrix of estimators for the factor model.

An explicit expression is given for the covariance matrix of the limiting distribution of the estimators of the parameters of the factor model. It is demonstrated that the limiting distribution of the vector containing the estimated error variances and the estimated coefficients holds for a wide range of assumptions about the true factors.

(with S. G. Pantula) Computational algorithms for the factor model.

Algorithms that are particularly suitable for samples that give zero estimates of some error variances are derived. A method of constructing estimators for reduced models is presented. The algorithms can also be used for the multivariate errors-in-variables model with known error covariance matrix.

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Wolter, K. M., and Fuller, W. A. (1982a), Estimation of the quadratic errors-in-variables model. Biometrika 69, 175-182.

Wolter, K. M., and Fuller, W. A. (1982b), Estimation of nonlinear errors-in-variables models. Ann. Statist. 10, 539-548.

SUMMARY OF CURRENT RESEARCH ACTIVITY AND INTERESTS

Leon Jay Gleser
Purdue University

My past research has mostly been concerned with functional relationship models in a multivariate context. I have two published papers in this area:

Gleser, L.J. and Watson, G.S. (1973). Estimation of a linear transformation. Biometrika 60, 525-534.

Gleser, L.J. (1981). Estimation in a multivariate "errors in variables" regression model: Large sample results. Annals of Statistics 9, 24-44.

In addition, two of my Ph.D. students, A. K. Bhargava and John D. Healy, have written on functional relationship models. Bhargava's papers are referenced in Gleser (1981), while Healy's work appears in Psychometrika (1979) and the Journal of Multivariate Analysis (1980). With the exception of one of Bhargava's papers, the above mentioned papers all concern maximum likelihood and/or generalized least squares methods of finding point estimators for the parameters of models of the functional type (errors in variables), large-sample distributions of such estimators, and large-sample construction of confidence regions and tests for these parameters. Bhargava also obtained finite sample distributions for maximum likelihood estimators in the bivariate case.

Recently, I have been working on finding finite sample confidence regions and tests for the slope parameters in errors in variables models. A technical report "Confidence regions for the slope in a linear errors-in-variables regression model" (Purdue University, Department of Statistics, Mimeo Series #82-23) shows that without restrictions on certain incidental parameters, no confidence interval of fixed coverage probability and finite expected length for the slope can exist. However, if the ratio of the variance of the unknown means (nuisance parameters) to the error variance is bounded below, my large sample confidence interval [Gleser (1981)] can be modified to give fixed coverage probability. I am now working on extending these results to the matrix of slopes in multivariate errors in variables regression models.

I have a long standing interest in factor analysis. My interest is less concerned with theoretical questions about properties of statistical inference procedures for the parameters of factor analysis models than it is with the use and establishment of such models as a basis for psychometric theory and practice.

Finally, I have become interested in models, such as Dolby's (Biometrika 1976) ultrastructural model, which unify functional and structural models, and am interested in finding general methods for estimating and testing parameters of such models. I have two Ph.D. students working on aspects of this problem, including a study of competing algorithms for calculating maximum likelihood estimators of the parameters.

J.C. Gower - Current Research Interests

Current research interests are in studying the properties of Euclidean and non-Euclidean distance matrices. The aim is to prove conjectures concerning bounds on the number of dimensions that can be fitted when using various criteria for metric multidimensional scaling. Euclidean data presented as an nxn distance matrix can always be fitted exactly in n-1 dimensions. It is easy to show that non-Euclidean data can never be fitted in more than n-2 dimensions. The problem is to tighten this bound and to designate the class of fitting-criteria for which the bounds hold. Associated with this is a study of the metric and Euclidean properties of classes of similarity matrices.

Other work ~~combines~~ continues an interest in the analysis of asymmetry by least-squares and by "non-metric" methods. This involves the study of skew-symmetric matrices and their geometrical presentation and also spectral properties of patterned skew symmetric matrices. A further line of attack is via the unfolding of asymmetric square matrices, which leads to interesting algebraic investigations and to novel graphical methods of representation. The basic idea is that a reduction in dimensionality may be paid for by representing each sample point more than once.

The general study of 3-way models and computational algorithms for fitting them is a third interest - this covers the Individual Scaling/Generalised Procrustes area.

Current Research Interests

THE STATISTICAL DETECTION AND DESCRIPTION OF ALLOMETRY

Pierre Jolicoeur

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My current research includes two major directions : one is the critical application of existing bivariate and multivariate methods in biological fields, like comparative mammalian neurobiology, where such methods have been little used or understood and where they can still produce original and important biological results; the other direction is the modification of existing techniques or the development of new techniques in cases where current procedures appear to have distinct practical shortcomings and fail to extract enough of the information in which biologists are interested.

Originally trained as a zoologist, I applied multivariate methods at first to differences between geographic races (Jolicoeur, 1959) and to size and shape variation (Jolicoeur and Mosimann, 1960). However, I became rapidly convinced that such problems were too strictly descriptive and did not exploit fully enough the rich interpretative possibilities of multivariate techniques. Consequently, many of my later applied works (Jolicoeur, 1963b, 1963c; Baron & Jolicoeur, 1980; Jolicoeur & Baron, 1980; Pirlot & Jolicoeur, 1982) have involved quantitative studies of functional animal morphology, the word functional having a biological meaning here and indicating that the biologist is striving to understand the role played by each part of a living animal and the dynamic relationships between parts. Multivariate analysis is particularly rewarding in statistical studies of functional morphology because it allows the biologist to have an '*organismic*' (that is a 'unified') view of living beings is all of their complexity and variability.

My first personal experience with allometry, when I was working on my Ph.D. thesis at the University of Chicago, made me aware of three important practical facts : (1) the frequency distribution of body dimensions of living organisms often agrees well with the lognormal model; (2) the logarithmic transformation makes the covariance matrix invariant to linear scale changes of original variates; (3) the most pronounced trend of variation in random samples from natural biological populations corresponds generally to age and size. These three facts suggested that the equation of the first principal axis or principal component of the logarithmic covariance matrix might constitute a suitable multivariate generalization of the allometry equation (Jolicoeur, 1963a). This proposal has been questionned by Hopkins (1966), who preferred factor analytic methods and objected to the sensitivity of principal components to large disproportionate '*discrepancy variances*' (in Hopkins' terminology; one would now generally speak of residual variances about a structural relationship). The question has been ably reviewed by Sprent (1972). However, Hopkins' formulation of

allometry was based on the assumption that structural variation has rank one (corresponding to the hypothesis of a single general factor in the analysis of psychological data), and this assumption is generally unrealistic in the case of biological data : except in the trivariate case (well discussed by Barnett, 1969), which is interesting but somewhat atypically simple, I can hardly find examples of morphometric data where the rank one assumption appears to be justifiable. In my opinion, however, the failure of the single-factor model does not entail the rejection of the allometry concept : allometry has to be interpreted as a dominant trend of variation on which lesser trends, corresponding to other factors or principal components, are superimposed.

Believing that it should be easier to get a complete understanding of allometry in the bivariate than in multivariate cases, I spent several years exploring the utilization of the bivariate normal major axis and of the bivariate linear structural relationship (Jolicoeur, 1965, 1968; Jolicoeur & Mosimann, 1968; Jolicoeur & Heusner, 1971; Jolicoeur, 1973, 1975). My interests have recently turned again to multivariate allometry and to the relative suitability of principal components, of factor analysis and structural relationships, and of size and shape methods, such as those developed by Dr. James E. Mosimann (Mosimann, 1970; Mosimann & James, 1979; Mosimann, Malley, Cheever & Clark, 1978).

Principal component analysis has several distinct advantages : (1) the equation of the first principal axis yields an explicit and unified description of the shape changes which may be expected to accompany size differences; (2) computations are easily, accurately and rapidly carried out and, unlike those of factor analysis, never yield mathematically unacceptable estimates; (3) asymptotic direction tests are available (Anderson, 1963; Kshirsagar, 1961). However, if the model prevailing in reality is factor analytic and some residual variances are clearly larger than others, principal component analysis could yield biased estimates of allometry exponents, as discussed by Hopkins (1966).

Factor analysis and structural relationships appear attractive in principle for the study of morphometric data because the idea that part of the variance of each variate is specific to that variate seems biologically realistic and consonant with a hierarchical conception of biological development. In practice, however, factor analysis and multivariate structural relationships exhibit a most unsatisfactory feature : the frequent occurence of unacceptable negative estimates for residual variances ('Heywood cases'). This problem stili seems not to heve been given general and truly satisfactory solutions : even second-order derivative iterative algorithms do not prevent the difficulty, and proposed diversions seem to give too much weight to what may be a trivial and sometimes accidental (but nevertheless very troublesome !) technical problem.

As for size and shape methods (Mosimann, 1970; Mosimann & James, 1979), they can play a useful confirmatory role but they appear to be better adapted to the detection of allometry than to its description. The conclusions obtained from size and shape techniques depend also on the choice of a size variable, much like the conclusions derived from principal components depend on the inclusion or exclusion of some variates from the analysis.

At the present time, and until the serious technical problems plaguing factor analysis and multivariate structural relationships receive satisfactory general solutions, I hold the opinion that principal components still constitute the best way to describe multivariate allometry, while size and shape techniques can play a useful confirmatory role in the detection of allometry.

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Summary of current research interests in functional and structural relationships

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1. Allometry and growth

A deterministic differential equation, special cases of which represent allometry and the Lotka-Volterra equation for interaction (competition, predator prey) between species leads to an invariant linear relationship between a set of variables $\underset{\sim}{y}$ (representing the sizes of organs or populations) and their logarithms. In fitting this relationship to data a suitable stochastic model must be developed. In introducing such relationships, Turner (Growth 42, 1978, 434-50) fitted them by linear regression. Regression techniques and their close relatives (principal components or generalised eigenvalues) fail to provide a satisfactory fit to such data although for two variables one version of canonical correlation analysis does succeed. A functional relationship model, close in spirit to that suggested by the canonical correlation analyses but which encompasses n-variate relationships has been developed and applied in joint work with R.L. Sandland in a paper in Growth (46, 1982, 1-11) and another to appear in Biometrics.

Our recent work on this problem includes fitting to further data, investigating the special case of canonical correlations as a link between "linear" (regression, principal components ...) techniques and our f.r. model and placing the model in the wider framework of models in which variables appear in more than one functional form.

Of potentially great interest is the development of techniques for fitting such relationships to longitudinal growth data.

2. Robust and distribution free estimation of functional relationships

I am interested in but as yet have not proceeded far with:-

a. The impact of grouping on robustness of F.R. estimation (ref. J.B. Copas, J.R.S.S.B., 34, 1972, 274-278).

b. The extent to which distribution free regression estimators such as that of Theil/Sen (ref. P.R. Sen, J.A.S.A., 63, 1968, 1379-1389) and those based on signs of residuals (ref. D. Quade, J.A.S.A., 74, 1979, 411-417) can be used or modified in estimating functional or structual relationships.

3. Circular functional relationships

Some recent joint work with Mark Berman on estimating the centre and radius of a circle has led to an interest in circular F.R.'s and S.R.'s although my main interest is in other methods of fitting circles and other conic sections.

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Summary of interests in the subject area of the workshop

My main responsibility during the past years was to provide for statistical consultation in animal husbandry and related fields. It may be clear that this position is not particularly gravitated towards research activities. However, a limited amount of time could be spent to do some research, mainly in connection with practical problems that arise during consultation. At several occasions I had thus to pay attention to problems of comparative calibration and to the related literature. I found a paper by Youden (1) very useful and stimulating as a practical introduction. Inevitably the subject area leads one to the models and methods of Grubbs (2), and of functional and structural relations and factor analysis. I expected the one-factor model to be very useful because of its flexibility for modelling systematic differences and measurement errors. In my examples, however, this model always showed a bad fit to the data. In a reader reaction (4) to the paper of Theobald and Mallinson (3) I called attention to this phenomenon, which was essentially due to a variance component structure in the errors. The existence of such variance component structures, which appears to be quite common in practice, does not only ask for adaptation of estimation and testing methods, but first of all for a careful definition of the models considered to be relevant to the problem. I presented some examples and expressed my views with respect to this point in a paper read before the Dutch region of the Biometric Society 5, in Dutch; translated title: "Estimating Functional and Structural Relations: looking for applications of the theory"). During the workshop I intend to call attention to practical problems in establishing functional relationships (6).

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Summary: Rather frequently in biometrical practice the study of relationships between variables is in order. Almost always it is appropriate to apply regression models to establish these. Cases with underlying exact relations between mathematical variables, which are measured with error, appear to occur only seldomly. In this paper attention is paid to some practical examples. Especially problems of definition of the relations and the errors involved, design problems, and the practical use of the estimated relationships will be discussed.

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

University of Dundee

24 August - 9 September 1983

Current Research Interests of Karl G Jöreskog

I am interested in all aspects of models for factor analysis and linear structural relationships, including the identification, estimation and testing of such models. I am also interested in real applications of such models in the social and behavioral sciences. Together with Dag Sörbom I have developed the general LISREL model and the LISREL computer program, widely used all over the world to deal with problems of this kind. The latest version of LISREL, LISREL VI can be used to estimate factor analysis models, structural equation models and various mixtures of these using any of the following five methods: IV (instrumental variables), TSLS (two-stage least-squares), ULS (unweighted least squares), GLS (generalized least squares) and ML (maximum likelihood).

Current Research Interests and Activity

by Naoto Kunitomo*/

March 1983

I have been interested in linear functional and structural statistical relationships models especially in connection with the simultaneous equations system in econometrics. The dual structure of these two statistical models has been pointed out by Anderson (1976) in some special cases. In the class of limited information estimation methods, I have proposed a new asymptotic theory, called the large-K_2 asymptotics (here K_2 is the number of the excluded exogenous variables in a particular structural equation), which corresponds to the usual large sample asymptotic theory in a linear functional relationship model (Kunitomo (1980) and (1981), for example). The large-K_2 asymptotics may give some new suggestions on the statistical inference when the econometric model is fairly large.

As in the simultaneous equations model, some progress on the study of the distributions of alternative estimators has been made; finite sample results (Anderson et.al. (1982), for instance), asymptotic expansion of the distribution of estimator (Fujikoshi et.al. (1982), for instance), and the improvement of the ML estimator (Morimune and Kunitomo (1980), for instance), among many.

I am working on some statistical testing procedures including confidence intervals in the simultaneous equations system in connection with the linear functional and structural statistical models.

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H.N. Linssen

Current research interests

My current research in Functional Relationships concerns three topics:

1 Asymptotic distributions in FR's

With the aid of the relatively simple theory of 'minimum-sum estimation', asymtotic distributions of estimators in FR's, that are linear in the incidental parameters, can be derived, not only for identically normal errors but more general for a wide class of incompletely specified errordistributions. An interesting special case is the multivariate linear FR. In that case it seems possible to derive a consistent and explicit expression for the covariancematrix of the asymptotically normal distributed structural parameter-estimators. In literature these results are available only in the normal case.

2 FR's in systems theory

Suppose a multi-input, multi-output system can adequately described by an ARMA-model. Suppose further that the inputs are measured with (possibly non-Gaussian) error. The problem is to determine in a numerically feasible way the parameter estimates and the associated sampling distribution. Other relevant research topics are the testing of hypotheses in this situation and an evaluation of the FR-approach in comparison with a number of more or less ad-hoc methods, known from literature.

3 Inconsistency in nonlinear FR's

It is well-known that generalized least squares estimates for parameters in FR's, that are nonlinear with respect to the incidental parameters, are inconsistent.

I assessed the usefulness of a modified bootstrap-technique to reduce significant inconsistency for a special but typical nonlinear FR. The jackknife is of no avail in that case and in general.

Eindhoven, May 13,1983

RESEARCH INTERESTS

R.P. McDonald
Macquarie University

Over approximately twenty years I have been engaged in research on the classical common factor model, nonlinear common factor models, optimal scaling, general models for linear structural relations (analysis of moment structures), and latent trait theory (item response theory).

What I would describe as my main current research interest is in the extension of my recent work on linear and nonlinear factor analysis models with fixed regressors to cover general models for nonlinear structural relationships. I append a brief and informal conference handout that expresses the basic notions of the work. See also the references cited therein. In addition, I append a selection of other relevant references to my work.

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Nonlinear models for path analysis

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For Math. Psych. Conference,
Newcastle, November 1982

Abstract

A general nonlinear model for path analysis with observed variables is described. From the properties of two methods of fitting path-analysis models, it is suggested that a strictly nonlinear model containing latent variables cannot be developed. A mixed model with a nonlinear measurement part and a linear structural part is therefore suggested.

1. General linear model (observable variables)

Let $\underset{\sim}{V} = [\underset{\sim}{v}_1, \ldots, \underset{\sim}{v}_N]$ be a matrix of N observations of n random variables. The general path-analytic model is

$$(1.1) \qquad \underset{\sim}{v} = \underset{\sim}{\beta}\underset{\sim}{v} + \underset{\sim}{e}$$

where

$$\underset{\sim}{\beta} = [\beta_{jk}], \; n \times n$$

is a matrix of regression weights, with $\beta_{jk} = 0$ if there is no directed path from v_k to v_j, and $\underset{\sim}{e}$ is a vector of residuals.

The notion is that the regression of each component of $\underset{\sim}{v}$ on a subset of other components expresses the "causal influence" of the latter on the former. This notion requires considerable explication, but that will not be undertaken here.

Method I: From (1.1) we have

$$(1.2) \qquad (\underset{\sim}{I}_n - \underset{\sim}{\beta})\, \underset{\sim}{v} = \underset{\sim}{e} \,,$$

hence

$$(1.3) \qquad \underset{\sim}{v} = (\underset{\sim}{I}_n - \underset{\sim}{\beta})^{-1}\, \underset{\sim}{e}$$

hence

$$(1.4) \qquad \mathcal{E}\{\underset{\sim}{v}\underset{\sim}{v}'\} = (\underset{\sim}{I}_n - \underset{\sim}{\beta})^{-1} \mathcal{E}\{ee'\}\, (\underset{\sim}{I}_n - \underset{\sim}{\beta})'^{-1}.$$

It follows that we may fit the moment-structure (1.4) to the sample covariance or raw product-moment matrix $\frac{1}{N}$ VV' by a standard program for the analysis of covariance structures such as Jöreskog's LISREL or McDonald and Fraser's COSAN. HOWEVER, AS WILL BE SEEN, THIS TREATMENT DOES NOT YIELD FEASIBLE GENERALIZATIONS TO NONLINEAR RELATIONSHIPS.

Method II: Corresponding to (1.1) we write

$$(1.5) \qquad \underset{\sim}{V} = \underset{\sim}{\beta}\underset{\sim}{V} + \underset{\sim}{E}$$

where $\underset{\sim}{E} = [\underset{\sim}{e}_1, \ldots, \underset{\sim}{e}_N]$. Then

$$(1.6) \qquad \underset{\sim}{E} = (\underset{\sim}{I}_n - \underset{\sim}{\beta})\, \underset{\sim}{V}$$

and

$$(1.7) \qquad \mathcal{E}\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\} = (\underset{\sim}{I}_n - \underset{\sim}{\beta})\, \mathcal{E}\{\tfrac{1}{N}VV'\}(\underset{\sim}{I}_n - \underset{\sim}{\beta})' \,.$$

We may therefore fit (1.1) to $\frac{1}{N}$VV' by choosing $\underset{\sim}{\beta}$ to minimize a suitable function of

$$\frac{1}{N}EE' - (\underset{\sim}{I}_n - \underset{\sim}{\beta})\, \frac{1}{N}\underset{\sim}{V}\underset{\sim}{V}'(\underset{\sim}{I}_n - \underset{\sim}{\beta})' .$$

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General linear model with latent variables (McArdle, 1980)

Let

$$\underset{\sim}{v} = \begin{bmatrix} \underset{\sim}{y} \\ \underset{\sim}{x} \end{bmatrix}, \qquad \underset{\sim}{y} \text{ "observable", } m\times 1, \quad \underset{\sim}{x} \text{ "unobservable", } r\times 1$$

with $m + r = n$, and define

$$\underset{\sim}{J} = [\underset{\sim}{I}_m : \underset{m\sim r}{0}].$$

Then by (1.3)

$$(1.8) \qquad \underset{\sim}{y} = \underset{\sim}{J}(\underset{\sim}{I}_n - \underset{\sim}{\beta})^{-1}\underset{\sim}{e} ,$$

hence

$$(1.9) \qquad \mathcal{E}\{\underset{\sim\sim}{yy'}\} = \underset{\sim}{J}(\underset{\sim}{I}_n - \underset{\sim}{\beta})^{-1}\mathcal{E}\{\underset{\sim\sim}{ee'}\}(\underset{\sim}{I}_n - \underset{\sim}{\beta})'^{-1}\underset{\sim}{J}' .$$

Proof that this model is general (McArdle & McDonald, unpublished):

The recursive model for linear structural relations

$$\begin{aligned} A_0\underset{\sim}{y} &= \underset{\sim}{e}_0 + \underset{\sim}{B}_1\underset{\sim}{x}_1 , \\ (1.10) \qquad A_1\underset{\sim}{x}_1 &= \underset{\sim}{e}_1 + B_2\underset{\sim}{x}_2 , \\ &\cdots\cdots\cdots \\ A_{m-1}\underset{\sim}{x}_{m-1} &= \underset{\sim}{e}_{m-1} + \underset{\sim}{B}_m \underset{\sim}{x}_m \end{aligned}$$

is equivalent to McDonald's (1978) COSAN model

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$$(1.11)\qquad \mathbf{y} = \mathbf{A}_0^{*-1}\mathbf{B}_1^{*}\mathbf{A}_1^{*-1}\mathbf{B}_2^{*}\mathbf{A}_2^{*-1}\cdots\mathbf{A}_{m-1}^{*-1}\mathbf{B}_m^{*}\begin{bmatrix}\mathbf{x}_m\\ \mathbf{e}_{m-1}\\ \vdots\\ \mathbf{e}_0\end{bmatrix}$$

where $\mathbf{A}_j^{*} = \begin{bmatrix}\mathbf{A}_j & & & & \\ & \mathbf{I} & & & \\ & & \mathbf{I} & & \\ & & & \ddots & \\ & & & & \mathbf{I}\end{bmatrix}$

and

$$\mathbf{B}_j = \begin{bmatrix}\mathbf{B}_j & \mathbf{I} & & & \\ & & \mathbf{I} & & \\ & & & \ddots & \\ & & & & \mathbf{I}\end{bmatrix},$$

and is equivalent also to a case of McArdle's model (1.8), specifically

$$\mathbf{y} = [\mathbf{I}\,\mathbf{0}\,\mathbf{0}\,\ldots\,\mathbf{0}]\begin{bmatrix}\mathbf{A}_0 & -\mathbf{B}_1 & & & & \\ & \mathbf{A}_1 & -\mathbf{B}_2 & & & \\ & & \mathbf{A}_2 & -\mathbf{B}_3 & & \\ & & & \ddots & & \\ & & & & \mathbf{A}_{m-1} & -\mathbf{B}_m\\ & & & & & \mathbf{I}\end{bmatrix}\begin{bmatrix}\mathbf{e}_0\\ \mathbf{e}_1\\ \vdots\\ \mathbf{e}_{m-1}\\ \mathbf{x}_m\end{bmatrix}. \qquad (1.12)$$

Proof of the last statement is by tedious algebra. Since (1.10) and (1.11) are very general, (1.12) is very general, and since (1.8) contains (1.12), (1.8) is very general.

2. General nonlinear model (observable variables)

The general nonlinear path-analytic model is

$$(2.1)\qquad \mathbf{v} = \boldsymbol{\phi}(\mathbf{v}) + \mathbf{e}$$

where $\underset{\sim}{\phi}'(\underset{\sim}{v}) = [\phi_1(\underset{\sim}{v}), \ldots, \phi_n(\underset{\sim}{v})]$,

whose jth component is a single-valued function representing the regression of v_j on other components of v. Although there may be special cases other than the linear case, in which (2.1) may be solved explicitly as

$$(2.2) \qquad \underset{\sim}{v} = \underset{\sim}{f}(\underset{\sim}{e}) ,$$

it is clear that Method I does not generalise in any obvious way to nonlinear models.

On the other hand, following Method II we may in general write the analogue of (1.5)

$$(2.2) \qquad \underset{\sim}{V} = \underset{\sim}{\phi}(\underset{\sim}{V}) + \underset{\sim}{E} ,$$

where

$$\underset{\sim}{\phi}(\underset{\sim}{V}) = [\phi_j(\underset{\sim}{v}_i)],$$

whence

$$(2.3) \qquad \underset{\sim}{E} = \underset{\sim}{V} - \underset{\sim}{\phi}(\underset{\sim}{V})$$

and

$$(2.4) \qquad \mathcal{E}\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\} = \mathcal{E}\{[\underset{\sim}{V} - \underset{\sim}{\phi}(\underset{\sim}{V})]\,[\underset{\sim}{V} - \underset{\sim}{\phi}(\underset{\sim}{V})]'\} .$$

We therefore may fit (2.1) by choosing the parameters of $\underset{\sim}{\phi}(\underset{\sim}{V})$ to minimize a suitable function of

$$\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}' = [\underset{\sim}{V} - \underset{\sim}{\phi}(\underset{\sim}{V})][\underset{\sim}{V} - \underset{\sim}{\phi}(\underset{\sim}{V})]' .$$

Unfortunately, it appears that neither the logic of Method I nor that of Method II generalizes to strictly nonlinear models containing latent variables.

<u>A nonlinear latent trait model</u>

We write

$$(2.5) \qquad \underset{\sim}{Y} = \underset{\sim}{\Phi}(\underset{\sim}{X}) + \underset{\sim}{E},$$

where $\underset{\sim}{Y}$, n x N, is a matrix of N observations on n variables, $\underset{\sim}{X}$, r x N, is a set of N values of r latent variables (common factors) defined by the property that

$$(2.6) \qquad \mathcal{E}\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\} = \underset{\sim}{U}^2, \text{ diagonal n.n.d},$$

and $\underset{\sim}{\Phi} = [\underset{\sim}{\phi}_j(\underset{\sim}{x}_i)]$ is a set of prescribed single-valued functions.

McDonald (1979) showed that any such model can be fitted to $\underset{\sim}{Y}$ by minimizing either the ordinary least squares function

$$(2.7) \qquad \omega = \frac{1}{2}\,\mathrm{Tr}\,\{(\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}' - \mathrm{diag}\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}')^2\}$$

or the likelihood ratio function

$$(2.8) \qquad \ell = -\frac{1}{2}\log|(\mathrm{diag}\,\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}')^{-\frac{1}{2}}\ \tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'(\mathrm{diag}\,\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}')^{-\frac{1}{2}}|.$$

McDonald (<u>in press</u>) shows that the minimum point of either of these functions with respect to the parameters of $\phi_j(\cdot)$ is the same as the minimum point of

$$(2.9) \qquad \sigma = \frac{1}{2}\,\mathrm{Tr}\,\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\}\ .$$

In a special case, Etezadi-Amoli & McDonald (in press) have shown that it is best to alternate minimizing ω or ℓ with respect to $\underset{\sim}{X}$, and σ with respect to the parameters of $\phi_j(\cdot)$.

3. A mixed (nonlinear/linear) model for path analysis with latent variables

We assume (a) a nonlinear measurement model,

$$(3.1) \qquad \underset{\sim}{Y} = \underset{\sim}{\Phi}\{\underset{\sim}{X}\} + \underset{\sim}{E} \ ,$$

where $\underset{\sim}{Y}$, n x N, is a matrix of N observations on n variables, $\underset{\sim}{X}$, r x N, is a set of N values of r latent variables (common factors) defined by the property that the residual covariance matrix

$$(3.2) \qquad \mathcal{E}\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\} = \underset{\sim}{U}^2 \ ,$$

diagonal nonnegative definite, and $\Phi = [\phi_j\{\underset{\sim}{x}_i\}]$ is a set of prescribed single-valued functions, (b) a linear structural model

$$(3.3) \qquad \underset{\sim}{X} = \underset{\sim}{B}\underset{\sim}{X} + \underset{\sim}{\Delta}$$

where $\underset{\sim}{B}$, r x r, is analogous to $\underset{\sim}{\beta}$ above, and $\underset{\sim}{\Delta}$, r x N, is a matrix of residuals. By (3.1) and (3.3) we have

$$(3.4) \qquad \underset{\sim}{E} = \underset{\sim}{Y} - \underset{\sim}{\Phi}\{\underset{\sim}{X}\}$$

where

$$(3.5) \qquad \underset{\sim}{X} = (\underset{\sim}{I}_n - \underset{\sim}{B})^{-1}\underset{\sim}{\Delta},$$

so that

$$(3.6) \qquad \mathcal{E}\{\tfrac{1}{N}\underset{\sim}{E}\underset{\sim}{E}'\} = \mathcal{E}\{\tfrac{1}{N}(\underset{\sim}{Y} - \phi\{(\underset{\sim}{I}_n - \underset{\sim}{B})^{-1}\underset{\sim}{\Delta}\})(\underset{\sim}{Y} - \underset{\sim}{\phi}\{(\underset{\sim}{I} - \underset{\sim}{B})^{-1}\underset{\sim}{\Delta}\})' \ .$$

with respect to $\underset{\sim}{B}$, to the parameters of $\underset{\sim}{\Phi}$, and to $\underset{\sim}{\Delta}$. Given estimates

of $\underset{\sim}{B}$ and $\underset{\sim}{\Delta}$ we may use (3.3) to compute an estimate of $\underset{\sim}{X}$ if desired. Generalization on these lines to a fully nonlinear model does not seem feasible.

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RESEARCH INTERESTS IN FUNCTIONAL AND STRUCTURAL RELATIONSHIPS

1. Estimation of Polynomial functional relationships

We consider the polynomial function $\eta = \beta_0 + \beta_1\xi + \ldots + \beta_k\xi^k$ of a non-stochastic variable ξ. The parameter vector $\beta' = (\beta_0, \ldots, \beta_k)$ is to be estimated based on n observed pairs (x_1, y_1), ..., (x_n, y_n), where $x_i = \xi_i + \delta_i$, $y_i = \eta_i + \epsilon_i$ and the (δ_i, ϵ_i) have zero means and a common covariance matrix Ω. A consistent estimator of β is obtained for any degree k when the (δ_i, ϵ_i) are multivariate normal with Ω known. For the quadratic functional relationship $(k = 2)$, a simple consistent estimator which needs no normality assumptions on the (δ_i, ϵ_i) is constructed. This has been a joint research with L.K. Chan. Wolter and Fuller (1982) discussed also the quadratic functional relationship.

2. Multivariate functional relationships

We examine various methods for constructing unbiased estimating equations for estimating the parameters in a multivariate functional relationship when the error variances and covariances are not necessarily homogeneous. These include the modified likelihood of Chan and Mak (1983b), Morton's (1981) generalized likelihood procedure, and the generalized least-squares approach (Chan, 1980; Sprent, 1966). Asymptotic properties of an estimator based on a set of derived estimating equations are also studied (see also Gleser 1981; Mak 1981). This work is jointly done with N.N. Chan.

3. Generalized least-squares approach in models with correlated errors

Sprent (1966) proposed a generalized least-squares approach

for estimating functional relationship models when the errors at different data points may be correlated. Some large sample properties of this estimation method were studied for the bivariate case and the results summarized in Mak (1983). Some extensions of this work are being considered (Chan and Mak 1983b).

4. Others

(i) Maximum likelihood estimation of a multivariate linear structural relationship (Chan and Mak 1984).

(ii) General problem of estimating a bivariate structural relationship (possibly non-linear).

T.K. MAK

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Current Research Interests R. Morton

Since I joined CSIRO in 1978 my research has been largely motivated by problems arising from statistical consulting. Models for the development times Y of insects [1] and wheat [2] were of the form

$$\int_0^Y r(\underset{\sim}{X}(t),\underset{\sim}{\theta})dt - 1 = \varepsilon ,$$

where r is rate of development depending on a random environmental vector $\underset{\sim}{X}$ and an unknown parameter vector $\underset{\sim}{\theta}$, and ε is a random error. The left hand side may be thought of more generally as a functional $g(Y,\underset{\sim}{X},\underset{\sim}{\theta})$. Estimating equations were derived for $\underset{\sim}{\theta}$.

For a linear functional relationship, we may 'eliminate' the incidental parameters and consider estimating equations derived from pivot-like functional $g = Y - \alpha - \beta X$. A general method for constructing estimating equations in the presence of many incidental parameters was proposed in [3]. By restricting the number of estimating equations to those corresponding to the parameters of interest the inconsistency of maximum likelihood estimators was avoided. Some results related to likelihood and least squares theory were included.

In [4] this idea was applied to a multivariate extension of the ultra-structural relationship of Dolby [5] and Cox [6], which included the pairwise linear relationship of Barnett [7]. The method led to the same modification of the likelihood equations as had been suggested by Patefield [8].

Linear functional relationships occur in the estimation of isochrons for dating rocks. For the metamorphic rocks analysed in [9] there was a good indication of the error variance-covariance structure which was non-standard. The possibility of a fixed point on the line was taken into account.

I am also interested in various regression problems, including survival curves, bioassay, nonlinear regression, calibrating trap catches and general

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Dundee Workshop: W M PATEFIELD

Consistency and Asymptotic Variances of Estimators

When linear structural relationships and equivalent factor analysis models are identifiable, by general likelihood considerations, the maximum likelihood estimators will be consistent and their asymptotic covariances, in theory, may be obtained using the information matrix.

For linear functional relationships and corresponding principal factor models, maximum likelihood estimators may not be consistent, and their consistency depends on the sequence of incidental parameters. In the linear ultrastructural model, inconsistent likelihood equations may be modified to produce consistent estimating equations.

Certain classes of models are found to have the same consistent parameter estimators whether the underlying model is based on the structural or functional assumptions. Further, the asymptotic covariances of estimators in linear models can be obtained using delta techniques and estimators of these covariances are independent of the underlying model in certain instances.

Application of delta techniques is often only possible when the data enters the estimating equations via sample moments. However, in other circumstances, such as fitting non-linear functional relationships, it is possible to obtain consistent estimating equations for the structural parameters and develop methods of obtaining asymptotic covariances.

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Dundee Workshop: W M PATEFIELD

Fitting Non-Linear Functional Relationships

Approximate techniques of fitting non-linear functional relationships rely on linearly approximating the relationship in the neighbourhood of the observed data points. Exact methods relying on the Newton-Raphson technique to simultaneously estimate the structural paramters $\underline{\alpha}$ of the relationship and the incidental parameters $\underline{\xi}$ (eg Dolby and Lipton, 1972) will be computationally difficult particularly for large sample sizes, n (as the number of incidental parameters increases with n). However, techniques which are feasible for large n are of particular interest when investigating the large sample properties of estimators using simulation.

With independent errors it is often possible to obtain exact estimates using a nested iterative scheme. As an illustration, consider a bivariate functional relationship

$$\eta_i = \eta(\xi_i,\underline{\alpha}).$$

Observations (x_i,y_i) are made on (ξ_i,η_i) with independent normal errors (δ_i,ε_i), $i = 1,2,\ldots,n$. If, in addition, $V(\delta_i) = V(\varepsilon_i)$ then least squares or maximum likelihood estimators of $(\underline{\xi},\underline{\alpha})$ are obtained at

$$\min_{\underline{\xi},\underline{\alpha}} S \quad \text{where} \quad S = \sum_i S_i \quad \text{and}$$

$$S_i(\xi_i,\underline{\alpha}) = \left\{y_i - \eta(\xi_i,\underline{\alpha})\right\}^2 + (x_i - \xi_i)^2$$

Now,

$$\min_{\underline{\xi},\underline{\alpha}} S(\underline{\xi},\underline{\alpha}) = \min_{\underline{\alpha}} S^*(\underline{\alpha})$$

where $$S^*(\underline{\alpha}) = \sum \min_{\xi_i|\underline{\alpha}} S_i(\xi_i,\underline{\alpha}) \qquad (1)$$

Minimization of $S^*(\underline{\alpha})$ over $\underline{\alpha}$ by Newton-Raphson, or using a modification as available in the N.A.G. library, requires for any given $\underline{\alpha}$, (i) evaluation of $S^*(\underline{\alpha})$ and (ii) the first and second derivatives of $S^*(\underline{\alpha})$. From (1) these can be obtained by minimizing $S_i(\xi_i,\underline{\alpha})$ over ξ_i in turn for each $i = 1,2,\ldots,n$. For given $\underline{\alpha}$, $S_i(\xi_i,\underline{\alpha})$ is minimized over ξ_i at one of the solutions to

$$-\frac{1}{2}\,\frac{\partial S_i}{\partial \xi_i} = \left\{y_i - \eta(\xi_i,\underline{\alpha})\right\} g(\xi_i,\underline{\alpha}) + (x_i - \xi_i) = 0 \qquad (2)$$

where $$g(\xi,\underline{\alpha}) = \frac{\partial\eta}{\partial\xi}(\xi,\underline{\alpha})$$

For a given model, a study of S_i should ensure that an iterative scheme can be developed to yield the $(\hat{\xi}_i(\underline{\alpha}),\hat{\eta}_i(\underline{\alpha}))$ on a relationship with structural parameters $\underline{\alpha}$ which minimize the distance to the ith data point (x_i,y_i). Denoting the resultant value of S_i minimized over ξ_i by

$$\min_{\xi_i|\underline{\alpha}} S_i(\xi_i,\underline{\alpha}) = S_i(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha})$$

then (1) can be evaluated as

$$S^*(\underline{\alpha}) = \sum_i S_i(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha})$$

First derivatives of $S^*(\underline{\alpha})$ are hence given by

$$\frac{\partial S^*}{\partial \alpha_s}(\underline{\alpha}) = \sum \left\{ \frac{\partial S_i}{\partial \alpha_s}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) + \frac{\partial S_i}{\partial \xi_i}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \quad \frac{\partial \hat{\xi}_i}{\partial \alpha_s}(\underline{\alpha}) \right\}$$

the latter term being zero by (2).

Second derivatives are given by

$$\frac{\partial^2 S^*}{\partial \alpha_r \partial \alpha_s}(\underline{\alpha}) = \sum_i \left\{ \frac{\partial^2 S_i}{\partial \alpha_r \partial \alpha_s}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) + \frac{\partial^2 S_i}{\partial \xi_i \partial \alpha_s}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \quad \frac{\partial \hat{\xi}_i}{\partial \alpha_r}(\underline{\alpha}) \right.$$

$$+ \frac{\partial^2 S_i}{\partial \alpha_r \partial \xi_i}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \frac{\partial \hat{\xi}_i}{\partial \alpha_s}(\underline{\alpha}) + \frac{\partial^2 S_i}{\partial \xi_i^2}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \frac{\partial \hat{\xi}_i}{\partial \alpha_r}(\underline{\alpha}) \frac{\partial \hat{\xi}_i}{\partial \alpha_s}(\alpha)$$

$$\left. + \frac{\partial S_i}{\partial \xi_i}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \quad \frac{\partial^2 \hat{\xi}_i}{\partial \alpha_r \partial \alpha_s}(\underline{\alpha}) \right\} \qquad (3)$$

the last term being zero by (2). Derivatives of S_i are easily obtained and differentiating (2), which equals zero at $\hat{\xi}_i(\underline{\alpha})$, for all $\underline{\alpha}$, we obtain

$$\frac{\partial \hat{\xi}_i}{\partial \alpha_r}(\underline{\alpha}) = - \frac{\partial^2 S_i}{\partial \xi_i \partial \alpha_r}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha}) \Bigg/ \frac{\partial^2 S_i}{\partial \xi_i^2}(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha})$$

Using this, (3) simplifies to

$$\frac{\partial^2 S^*}{\partial \alpha_r \partial \alpha_s}(\underline{\alpha}) = \sum_i \left\{ \frac{\partial^2 S_i}{\partial \alpha_r \partial \alpha_s} - \frac{\partial^2 S_i}{\partial \xi_i \partial \alpha_r} \quad \frac{\partial^2 S_i}{\partial \xi_i \partial \alpha_s} \Bigg/ \frac{\partial^2 S_i}{\partial \xi_i^2} \right\}$$

all evaluated at $(\hat{\xi}_i(\underline{\alpha}),\underline{\alpha})$.

If $\underline{\alpha}_j$ ($j = 0,1,2$, etc) denote successive iterates of $\underline{\alpha}$ when minimizing $S^*(\underline{\alpha})$ then computational efficiency will be achieved in the inner nest of the iterative scheme for minimizing $S_i(\xi_i,\underline{\alpha}_j)$ over ξ_i by using as starting values $\underline{\xi}_0 = \underline{x}$, $\underline{\xi}_j = \hat{\underline{\xi}}(\underline{\alpha}_{j-1})$, $j = 1,2$, etc., where $\hat{\xi}_i(\underline{\alpha}_j)$ is the value of ξ_i which minimizes $S_i(\xi_i,\underline{\alpha}_j)$. (ie the ξ_i obtained at one iteration when minimizing $S^*(\underline{\alpha})$ are used as starting values in the next iteration). Further computation efficiency may also be achieved by obtaining $\underline{\alpha}_0$ by a suitable approximate fitting technique.

The above procedure may be illustrated by fitting a rectangular hyperbola where it is found that (2) can be solved to machine accuracy in usually about three iterations.

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Summary of current research interests for workshop on functional and structural relationships and factor analysis at the University of Dundee.

R. L. Sandland, CSIRO, Division of Mathematics and Statistics.

I have been working with Dr. David Griffiths on functional relationship models in generalisations of the simple allometry equation. The motivation for this work was the discovery that least squares fitting of models of the form

$$\sum_{i=1}^{k} \beta_i \log y_i(t) + \sum_{i=1}^{k} \alpha_i y_i(t) + \gamma t = 1 \qquad (1)$$

, where $y_i(t)$, $i = 1, \ldots\ldots, k$ is the size of the i th organ or population at time t, gave a very poor fit to data analysed by Turner (1978). Other regression based and multivariate linear techniques also failed; these included regression models of the second kind and generalised eigen value methods (of which principal components is a special case).

The reason for the failure of these techniques is that $y_i(t)$ enters the invariant (1) above in two highly correlated functional forms. Regression based fitting procedures force spurious invariants of the form $\beta_i \log y_i + \alpha_i y_i$ $i = 1, \ldots, k$, where β_i and α_i have opposite signs, to dominate the analysis. Least squares was shown to be an inappropriate penalty function (Griffiths and Sandland, 1982).

The derivation of the invariant relationship (1) was based on a generalisation of allometry to allow for interactions between organs or populations, using an extension of the deterministic Lotka - Volterra equations. The stochastic structure implicit in regression based techniques sees independent errors tacked on as an afterthought to the left hand side of (1).

The aim of the work was to find a natural statistical framework for models of this type. Functional relationship models provided the basis for our approach. The general problem of functional relationships in which the variables appear in more than one functional form is the general theoretical context which we hope to explore further.

A specific example in the context of model (1) was to assume that, for each t_j, functions $F_i = \alpha_i y_i(t_j) + \beta_i \log y_i(t_j)$, are jointly normally distributed $N(\underset{\sim}{\theta_j}, \underset{\sim}{V})$, where $\underset{\sim}{\theta_j}' = (\theta_{1j}, \theta_{2j}, \ldots\ldots, \theta_{kj})$.

$F_i(t_j)$ is assumed independent of $F_i(t_k)$ for each t_j and t_k.

This is reasonable in cross - sectional growth studies (common with allometric data) but, in longitudinal multivariate growth data, more sophisticated models are required, probably involving multivariate extensions of the stochastic differential equation models of Sandland and McGilchrist (1979).

Transformation from the unobservable F_i to the observable y_i yields a likelihood function subject to the parametric constraints $\sum \theta_{ij} + \gamma t_j = 1$ for each j. The transformation also restricts the space of permissible parameter values as sign changes in the Jacobian invalidate the transformation.

Maximization of the likelihood function requires assumptions to be made about V. In one example studied, the qualitative interpretations differed when different assumptions were made about V . As these interpretations are of considerable biological importance, this presents a difficult question in the art of data analysis. The reasons for this difference are still being sought. Perhaps the model is inadequate for the data and the difference in interpretation is simply a warning. This approach has been written up in Griffiths and Sandland (1983).

A seemingly simpler set of assumptions, namely that $\log y(t_j) \sim N(\phi_j, V^*)$ involves maximization of a likelihood function subject to an awkward nonlinear constraint. This leads to computational, if not theoretical, difficulties in the maximization; the approach has not yet been fully explored.

One of my other research interests is the use of recursive residuals and other tools as regression diagnostics. In many cases when regression models are used routinely, functional relationship models should in fact be used. However, the potential user is faced with a dearth of diagnostic tools. I would like to consider two related aspects of this matter: can any of the general linear model diagnostics be adapted for use in functional relationship models?; if not, is it possible to develop special purpose diagnostics? I have not spent much time on these problems but hope to have thought more along these lines before the workshop.

My other research interests, not particularly relevant to the workshop, include capture - recapture models and numerical classification.

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Summary of my current research interests prepared for the WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS.

Hans Schneeweiss, Munich

I am professor of econometrics and statistics at the University of Munich. In 1971 I published a general text book on econometrics (in German), but for the last few years my research interest has switched to models with errors in the variables as they appear in econometrics and elsewhere.

In the beginning I was mainly interested in the asymptotic properties of estimators and did some work in computing asymptotic variances (see 7, 8, 12, 13), but more recently I also looked into the small sample and exact properties of estimators. When the error-ridden variable follows a trend, the ordinary least squares estimator of the slope of a regression line β becomes a consistent estimator, quite in contrast to the usual textbook situation. In fact, the least squares estimator has the same asymptotic variance as almost all the other estimators that are typically suggested in the context of errors in the variables (e.g. least squares estimator adjusted for the error variance, instrumental variable estimator with the trend variable as instrument etc.). However, if one expands the bias of these estimators as a power series of the reciprocal of the sample size, then differences show up and the least squares estimator is inferior to the other estimators (see 10). This finding, which was derived analytically, was supported by a Monte Carlo study (14).

Another paper (11) deals with Creasy's exact t-test for β (see 1). I tried to clear up a few misunderstandings that have crept into the literature on this subject and also suggested how the test might be extended to the case of a multiple linear relationship. Right now one of my students, R. Galata, is investigating the power function of Creasy's test and of related tests. One funny aspect about Creasy's procedure is that it produced a confidence region for β which typically consists of two (or three) intervals. One can avoid this anomaly by retaining only the most plausible interval, i.e. the interval that contains the ML-estimator of β. It remains an unanswered question by how much the confidence level is reduced thereby. Another approach to the construction of approximate small sample confidence intervals is suggested by the work of Sprott (15). Recently I tried to apply his idea to the marginal likelihood function

for the linear functional relationship as developed by Kalbfleisch and Sprott (2), but I have not yet got any definite results.

It seems to me that likelihood methods as applied to the linear relationship are still worth exploring despite the large amount of published work in this field. E.G. a puzzling result which I found out recently is the fact that the marginal likelihood, as referred to above, has a Fisher's information measure which is not in accordance with the asymptotic variance of the ML-estimator. I also applied the ML-procedure, in an unpublished paper, to the case of a multiple linear structural relation with replicated data and designed a likelihood ratio test for testing the occurrence of errors in the equation (in addition to errors in the variables).

Apart from these more specialized research activities I am preparing a textbook on linear models with errors in the variables. It will be written in German and will start at a rather elementary level. But I am trying to cover most of the results that have been accumulated during the last years. A kind of survey article has appeared in German (9).

I should also like to mention that one of my students, Dr. E. Nowak, did his dissertation (in German: 'Habilitation') on time series models with errors in the variables (4,5,6). His work is in the same line as Maravall's (3), but on a more general level, using quite different methods. He solved the problem of identifying time series models.

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RESEARCH INTERESTS

Statistical model specifications in econometrics
Errors-in-variables and latent variables models
Dynamic latent variables models
Systems theory and latent variables models; the Frisch forumulation
Identification and systems realisation theory
Dynamic modelling in econometrics
Asymptotic statistical inference
Modelling the monetary sector of the U.K. economy

FASRAFA - DUNDEE 1983

P. Sprent. Research Interests

I am interested in unification of different approaches to 'errors in variables' models following the proliferation in recent years both in specification of models and in estimation methods that often lead to broadly the same result. For example: how important is the distinction between 'functional' and 'structural' relationships?

I would hope that at the workshop some attention might be given to standardization of notations in the topics with which we are concerned.

Other topics in which I am interested but have not at this stage done any work of substance include

a) Non-linear functional relationships;

b) Robust or distribution free methods for 'errors in variables' models.

Summary of Current Research Interests

prepared for the

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

DUNDEE, 24 August - 9 September 1983

by

Chris Theobald, University of Edinburgh

Multivariate Linear Structural Relationships

Maximum likelihood estimation with various assumptions about the variance-covariance matrix of the departures from the relationships (known up to a constant factor, diagonal, arbitrary) and with certain patterns of fixed effects.

Distributions of likelihood ratio tests of dimensionality: the standard asymptotic theory does not apply since the null hypothesis corresponds to a set of boundary points of the parameter space.

Likelihood ratio tests for a specified matrix of coefficients, possibly in the presence of further, unspecified relationships; corresponding confidence regions.

Examination of distributional assumptions using residual analyses and probability plots.

Comparative calibration and its connexions with factor analysis and mental test theory. (See Theobald, C.M. and Mallinson, J.R. Comparative calibration, linear structural relationships and congeneric measurements. Biometrics, 34 (1978), 39-45). Generalization to multivariate properties.

Applications of Functional and Structural Relationships

Functional relationships arising from the combination of regression analyses, particularly concurrent regressions, models for variety x environment interactions in crop yields, and biological assays. (For the last of these see Vølund, A. Combination of multivariate bioassay results. Biometrics, 38 (1982), 181-190, and references therein.)

Estimation of variance functions in regression using sets of replicate responses: this can be regarded as the estimation of a non-linear functional relation. (See Raab, G.M. Estimation of a variance function, with application to immunoassay. Applied Statistics, 30 (1981), 32-40.)

Testing Murray's Law for the diameters of bloods vessels and bronchi at bifurcations. Murray's Law states that the cube of the diameter of a parent vessel in which flow is laminar equals the sum of the cubes of the diameters of the daughters. Similar laws (with exponents less than 3) have been suggested in the cases of diffusion and turbulent flow. Data on diameters at bifurcations might be modelled by a non-linear functional relationship with only two structural parameters (the exponent in the relationship and a common variance or proportional variance) and provide a testing ground for methodology for non-linear relationships. (For a review of work on the "law" see Sherman, T.F. On connecting large vessels to small: the meaning of Murray's Law. Journal of General Physiology, 78 (1981), 431-453.)

To all invited participants

Circular A

Workshop on Functional and Structural Relationships and Factor Analysis

University of Dundee,

Dundee, Scotland.

24 August - 9 September 1983

This circular is to let you know that planning for the Workshop is going ahead satisfactorily, to answer one or two queries we have had and to mention one or two developments since the formal invitations were issued.

Wives and families

Several participants have asked about arrangements for bringing spouses and/or families. They will be most welcome. A number of twin-bedded rooms are available if required in Chalmer's Hall, the University residence where the workshop is being held. Full board rates (including all meals) will be £14.30 per person per day, reducing to £11.20 if lunch is not required and to £8.20 for bed and breakfast only. All rates include VAT and service charges as appropriate. Half rates will be charged for children aged between 5 and under 15 and there is no charge for children under 5. Firm bookings for family members will be requested later (probably about May/June 1983).

Excursions and Workshop Dinner

We intend to arrange excursions on each of the Sundays in the Workshop period and if possible one evening excursion to an Edinburgh Festival Performance. There will also be an official Workshop Dinner. Details of dates, costs and venues for these activities will be circulated several months before the start of the workshop.

Open Forum Conference

As intimated when invitations were issued the main workshop is restricted to invited participants but there will be an Open Forum Conference from 7 - 9 September for which anybody interested may register. In our invitations we expressed the hope that as many invited workshop participants as possible would present a paper or lead a discussion session at the open forum. If for any reason you will not be able to attend that part of the proceedings please let me know by 15 January 1983. If I have not heard from you by that date I shall include your name among those participating in the Open Forum in the information sheet announcing the Open Forum. I very much hope you will take part so that as many as possible may benefit from this unique gathering of experts in the field. Titles of papers, etc. for the Open Forum will not be required until 1 May 1983 (along with an abstract, and the summary of your current research activity requested in your invitation to the workshop).

P. SPRENT.

Department of Mathematical Sciences,
The University,

TO ALL INVITED PARTICIPANTS

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

UNIVERSITY OF DUNDEE

24 August - 9 September 1983

Information current at 31 March 1983

Acceptances

The following have accepted invitations (some are provisional and one or two will attend for a limited period only). The majority are expected to attend for all or most of the period. Two replies are still awaited.

T.W. ANDERSON	W.A. FULLER	R. MORTON
V.D. BARNETT	L.J. GLESER	J.E. MOSIMANN
D.J. BARTHOLOMEW	J.C. GOWER	W.M. PATEFIELD
MICHAEL BARTLETT	D. GRIFFITHS	R. PRENTICE
R.A. BROWN	E.H. INSELMANN	G. ROSS
N.N. CHAN	A.A.M. JANSEN	D. SANDLAND
J.B. COPAS	P. JOLICOEUR	H. SCHNEEWEISS
G.R. DOLBY	K.G. JÖRESKOG	A. SPANOS
B.S. EVERITT	H. LINSSEN	P. SPRENT
P.R. FISK	T.K. MAK	C. THEOBALD
	R. McDONALD	

Sponsorship and Funding

In addition to financial support from the U.K. Science and Engineering Research Council (SERC) and the backing of the Royal Statistical Society and the U.K. Committee of Professors of Statistics we are pleased to acknowledge a grant from the U.S. Army European Research Office.

Workshop arrangements

While flexibility will be a keynote of the workshop to allow wide discussion of research interests it is hoped most participants will agree to do one or more of the following:

(a) Present a specialist paper at the workshop;

(b) Present a more general interest paper at the Open Forum (7 - 9 September);

(c) Lead or organize a symposium type workshop session.

Correspondence with several participants has already led to offers of papers. To aid organization will all participants please complete Form A attached to this circular and return it to reach me by 15 May 1983. Please note that participants were previously requested to submit by 1 May a summary of their current research interests (between 200 and 2,000 words as seems appropriate) together with relevant references to related work (their own and that of others). If you have not already sent such a summary please return yours with Form A. The summary will be photocopied for distribution prior to the Workshop.

Wald Memorial Lectures

Professor T.W. Anderson gave the 1982 Wald Memorial Lectures on the very topics of this Workshop. He has kindly agreed to make copies available to all who accepted invitations to the Workshop. If you have not already received a copy you should do so in due course. This material is a brilliant exposition of the present state of the subject.

Travel and Accommodation

As soon as your travel arrangements are finalized will you please fill in and return the attached "Form B". This should reach us not later than 1 July 1983 but it will be helpful if you can return it earlier.

If your spouse or other family members are coming to Dundee please indicate accommodation requirements for them on the form. The full board rate per person per day, including all meals, morning coffee and afternoon tea, is £14.30. As the conference is on a residential basis and it is felt informal mealtime discussions will form a useful part of the gathering only this full board rate is quoted for participants. However, family members may prefer a dinner, bed and breakfast only arrangement which will be available at £11.20 per day or bed and breakfast only at £8.20 per day. Children aged 5 to 15 are at half rates, and no charge for children under 5 subject to certain conditions.

Participants have been notified of the maximum contribution that will be made by SERC towards their accommodation expenses. This will be paid by us direct to the University authroities. Those paying for their accommodation from their own or other resources and for family members or for periods in excess of that covered by SERC grant must pay for such accommodation in advance. When we receive your completed "Form B" we shall notify you of the amount payable and the complete amount or a deposit should be forwarded to reach us not later than 15 August. The deposit will be 10 per cent of the amount due subject to a minimum of £20. Any balance must be paid on arrival in Dundee.

Conference second class concession return fares to Dundee from other British Rail Stations will be available. UK participants should tick the appropriate box on "Form B" if they require an application form. For overseas participants the procedure for concession fares is rather cumbersome and restrictions on use of tickets is rather irksome. However a variety of concession rail tickets for travel in the UK are only available overseas for visitors to Britain and if you intend to do any additional rail travel during your stay in the UK may be a good investment. They may be paid for in your own currency. Any good travel agent should be able to advise. If overseas participants do want more information on the conference concessions fares and procedures to get them please write to me asking for particulars as soon as possible.

Workshop dinner and excursions

There will be a workshop dinner for all invitees in Bonar Hall, University of Dundee, on Wednesday 31 August. The cost will be approximately £11 per head (including wines) but payment is not required until you arrive in Dundee. It would help if you could indicate on Form B whether you are likely to attend this dinner.

Excursions by coach will be arranged on Sunday, 28 August and Sunday, 4 September to Highland Resorts. If possible there may be evening trips to the Edinburgh International Festival. These will be arranged on an ad hoc basis depending on individual interests and programme arrangements.

Enquiries Please

The perfect information circular and forms have yet to be devised! Please do not hesitate to ask if we can help in any way. Further information about Dundee and how to get here will be sent with the pre-workshop bulletin which we hope to despatch about one month in advance of the workshop.

31st March 1983 P. SPRENT.

FORM A

Please complete and return to reach us by 15 MAY 1983

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

UNIVERSITY OF DUNDEE

24 August - 9 September 1983

Return on completion to:

Professor P. Sprent,
Department of Mathematical Sciences,
The University,
DUNDEE DD1 4HN,
Scotland.

1. NAME: ....

2. EXPECTED DATE OF ARRIVAL IN DUNDEE: ....

3. EXPECTED DATE OF DEPARTURE FROM DUNDEE: ....

4. IF WILLING TO PRESENT PAPER AT WORKSHOP PLEASE INDICATE TITLE

   ....

   ....

   (Normal time will be 1 hour but if you wish a shorter/longer time please indicate: .... minutes. We reserve the right to ask you to amend this time if it leads to programming difficulties.)

5. IF WILLING TO ORGANIZE A WORKSHOP SYMPOSIUM DISCUSSION (E.G. A "MORNING" "AFTERNOON" OR "DAY" SESSION FOR GENERAL DISCUSSION OF A TOPIC) PLEASE INDICATE TOPIC AND SUGGESTED LENGTH OF SYMPOSIUM:

   ....

   ....

6. TO HELP OUR PLANNING OF WORKSHOP ACTIVITIES PLEASE TICK ANY (AS MANY AS YOU PLEASE) OF THE FOLLOWING AREA THAT REPRESENT YOUR PARTICULAR INTERESTS:

   A. Inference problems in functional and structural relationships;

   B. Generalizations from one to several relationships;

   C. Notation and terminology;

Continued overleaf....

D. Relations between functional and structural models and those of factor analysis;

E. Scaling and invariance properties in factor analysis;

F. Practical applications to real data sets;

G. Applications of techniques developed in one field of application to other fields;

H. Relevance of these methods to calibration problems;

I. Extension to non-linear models;

J. System of equations in econometrics;

K. Any other relevant topic. Please specify briefly:

....

....

7. IF NOT ALREADY SENT, PLEASE RETURN A SUMMARY OF CURRENT RESEARCH INTERESTS (200 TO 2,000 WORDS READY FOR PHOTOCOPYING) AS REQUESTED IN THE CIRCULAR.

8. IF WILLING TO PRESENT A PAPER AT THE OPEN FORUM (7 - 9 SEPTEMBER) PLEASE GIVE TITLE:

....

....

OPEN FORUM PAPERS FROM WORKSHOP PARTICIPANTS WILL NORMALLY BE 30-45 MINUTES (EXCEPTIONALLY 1 HOUR). PLEASE INDICATE TIME YOU WOULD LIKE .... MINUTES.

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

UNIVERSITY OF DUNDEE

24 August - 9 September 1983

Return on completion to:-

Professor P. Sprent,
Department of Mathematical Sciences,
The University,
DUNDEE DD1 4HN,
Scotland.

1. **NAME:** ....

2. **EXPECTED DATE OF ARRIVAL IN DUNDEE:** ....

3. **LIKELY TIME OF ARRIVAL (IF KNOWN):** ....

4. **EXPECTED DATE OF DEPARTURE FROM DUNDEE:** ....

5. **NAMES OF SPOUSE AND/OR OTHER FAMILY MEMBERS ACCOMPANYING INVITEE:**
(Please state age of any family member less than 16 years old)

   (1) ....

   (2) ....

   (3) ....

   PARTICIPANTS ATTENDING UNACCOMPANIED BY FAMILY MEMBERS WILL NORMALLY BE ALLOCATED SINGLE ROOMS AND HUSBANDS AND WIVES TWIN ROOMS. PLEASE INDICATE ANY DIFFERENT REQUIREMENTS AND REQUIREMENTS FOR OTHER FAMILY MEMBERS. ALSO INDICATE ANY SPECIAL DIETARY REQUIREMENTS (E.G. VEGETARIAN)

   ....

   ....

   ....

   ....

6. **DO FAMILY MEMBERS (OTHER THAN YOURSELF) REQUIRE**

   (1) **Full Board?** ....

   (2) **Dinner/Bed/Breakfast?** ....

   (3) **Bed and Breakfast only?** ....

7. ☐ PLEASE TICK IF YOU EXPECT TO ATTEND OFFICIAL WORKSHOP DINNER (31 AUGUST).

8. U.K. PARTICIPANTS ONLY

☐ DO YOU REQUIRE AN APPLICATION FOR B.R. CONFERENCE CONCESSION RAIL FARES? (Tick if required).

9. OVERSEAS PARTICIPANTS ONLY

SEE CIRCULAR RE RAIL FARES. CONTACT US IMMEDIATELY IF YOU WANT INFORMATION ON CONFERENCE CONCESSION FARES (PROCEDURE COMPLICATED IF YOU LIVE OUTSIDE U.K. CONFERENCE CONCESSIONS COULD SAVE YOU MONEY IF YOUR ONLY INTENDED U.K. RAIL TRAVEL IS, SAY, LONDON/DUNDEE AND RETURN AND YOU CAN SPECIFY PRECISE DAY OF TRAVEL FROM LONDON TO DUNDEE.)

Circular C

TO ALL INVITED PARTICIPANTS

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

UNIVERSITY OF DUNDEE

24 August - 9 September 1983

Information current at 1 June 1983

Sponsorship

The Workshop is being organized by the Department of Mathematical Sciences at the University of Dundee under sponsorship from The Royal Statistical Society and The UK Committee of Professors of Statistics. Financial support has been obtained in the form of a research grant from the UK Science and Engineering Research Council with additional funding from the US Army European Research Office.

Programme

A provisional programme is given at the end of this circular. Times allocated to the various activities is to be regarded as approximate, but generally speaking the aim has been to allow ample time for discussion of papers.

Several discussion symposia are listed together with names of organizers. Our objective is to keep these as informal as possible but if any participant wishes to make a specific contribution to a particular symposium it might help the organizer to know about this in advance. We suggest that if you wish to do so you contact the organizer at the address given in the list of participants later in this circular. Likewise, organizers may wish to contact certain individuals who they feel could make special contributions to their symposium.

A number of slots in the programme are marked 'no formal activity'. It is our intention that these be used for informal meetings of members interested in particular topics; rooms will be available for such meetings. It is appreciated that some of the formal papers or discussion symposia may be of more interest to specialists in one particular area than to specialists in some other areas. While a prime aim of the workshop is to provide a framework for exchange of ideas we hope to keep that exchange on as informal a basis as possible and we hope that participants will not feel under any obligation to take part in an activity that is not of particular

interest to them, if they feel they can use that time for furthering research activity more relevant to them.

A final programme will be available to participants on arrival. PLEASE LET US KNOW IF ANY ENTRY IN THE PROVISIONAL PROGRAMME IN WHICH YOU ARE INVOLVED IS UNSATISFACTORY TO YOU.

Interests of Participants

You will recall that we asked for brief statements on research interests from all participants. These have been received from most of you and copies will be distributed to all participants on arrival in Dundee. Meantime we hope the coded list of fields of interest given in the list of participants in this bulletin will indicate broad areas of interest.

Accommodation and Meeting arrangements

As already announced accommodation and meals will be provided at Chalmers Hall, a University residence situated in Dundee town centre. (Marked as 62 and f on the enclosed maps).
Registration and the introductory morning session on the programme for Wednesday 24 August will be at Chalmers Hall. All other formal paper sessions and discussion symposia will be held on the main University Campus (Tower Building) which is about 10-15 minutes walk from Chalmers Hall and also served by City buses. For informal sessions there will be one or two rooms available at either Chalmers Hall or on the main University campus. Notice Boards will be available both at Chalmers Hall and in the University Tower Building for advertising any such informal activities. Changes to the main programme and other announcements will also be posted on these boards.

Tea and coffee making facilities will be provided in each study-bedroom. Morning coffee/afternoon tea will be available at the Tower Building/Chalmers Hall each day as appropriate.

Coin operated laundry facilities are available at Chalmers Hall.

For those arriving by train Chalmers Hall is about 400 metres from railway station, but a taxi might be advisable if you have heavy baggage. Car parking is difficult in the vicinity of Chalmers Hall, but arrangements can be made for parking of cars on the University Campus during the Workshop.

Incoming telephone calls for participants may be made to Chalmers Hall on the following Dundee numbers:-

26168 26169

In emergencies only if contact on these numbers proves impossible messages may be left at the Department of Mathematical Sciences in the University. The University number is 23181 and appropriate extensions are 214, 417 or 418. The dialling code for Dundee is 0382 for calls originating in the UK. Overseas callers using International Dialling facilities should enqire about codes locally, but after the appropriate code for international calls the code for Dundee will usually be 44-382 instead of 0382.

There will be a representative of the Department of Mathematical Sciences at Chalmers Hall from 4 pm on Tuesday 23 August to meet participants arriving that day. If you can let us know in advance by which train you are arriving we shall endeavour to meet you at the railway station, but we cannot guarantee to do this in all cases.

Social Activities

As already announced the official workshop dinner will be held at Bonar Hall, University of Dundee, on Wednesday 31 August. The cost including sherry beforehand and wine with the meal will be £11.00 per person payable on arrival at the workshop. A reduced price will be available for those requiring soft drinks in place of wine. Dinner will not be available at Chalmers Hall on the night of the workshop dinner.

Excursions are being arranged to the Scottish Highlands and to an Historic site (probably Falkland Palace) on the two Sundays in the workshop period. Some charge will be made for these excursions but we shall keep this as low as possible. Details are not yet finalized but will be available on registration.

If there is sufficient demand (minimum 5 persons) and weather permits scenic flights over the Higlands or Western Scotland will be arranged on Saturday 27 August. The cost per person subject to the above minimum (or a multiple of 5 persons) will be approximately £15.00 for a half hour flight or £30.00 for a one hour flight.

The Edinburgh International Festival takes place during the workshop period. Ticket availability varies between events. However, on most evenings it is possible to get tickets for at least one of the major performances at short notice. If there is sufficient demand it is hoped to provide mini-bus transport to/from Edinburgh on one or more evenings.

It is anticipated that a University sherry reception will be held on one of the nights during the 'Open Forum' section of the workshop (probably 7 September).

Fuller details of cultural, entertainment and scenic attractions in the Tayside/Fife regions will be available to participants on arrival.

Conference Rail Concession fares

For UK participants only we enclose application forms for conference concession rail fares. Please note carefully the instructions for applying and in particular that it is essential to state your date of travel to Dundee. Tickets are only valid for outward travel on that date.

A reminder

If you have not already returned "Form B" (detailing accomodation requirements) enclosed with our last circular please note that this should reach us by 1 July.

Further Circulars

Unless special circumstances arise we anticipate this will be the last general circular distributed before the start of the workshop, although we shall send out any additional relevant information as necessary. As already announced, if your accomodation is being paid from SERC funds we shall arrange payment direct to the University. For others we shall notify you of the amount due in terms of the information on your form B; a deposit will normally be required by 15 August with the balance due at registration.

Once again, if we have not made anything clear in this circular, please do not hesitate to contact me.

P Sprent

Department of Mathematical Sciences,
The University,
DUNDEE, DD1 4HN,
Scotland.

Encl. List of Participants.
Programme.

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

Addresses and lists of interests of those proposing to attend, as at 1 June 1983.

Interests

The list of interests is given in the line below each address, using the following codes:

A. Inference problems in functional and structural relationships.
B. Generalizations from one to several relationships.
C. Notation and terminology.
D. Relations between functional and structural models and those of factor analysis.
E. Scaling and invariance properties in factor analysis.
F. Practical applications to real data sets.
G. Application of techniques developed in one field of application to other fields.
H. Relevance of these methods to calibrtation problems.
I. Extension to non-linear models.
J. Systems of equations in econometrics.
K. Applications to categorical data.
L. Functional and structural relationships in non-normal situations.
M. Robust and distribution free estimators.
N. Circular functional and structural relationships.
P. Size and shape analysis, allometry, canonical analysis, discrimination.
Q. Large sample properties of estimators.
R. Data analytic tools for functional relationship models.
S. Forecasting, Bayesian analysis, dynamic models, use of higher moments in estimation.
T. Examination of assumptions in structural relationships.

Note: Categories A to J above are those listed on Form A circulated earlier. The remaining categories were listed on that form by various participants as "other interests". In one or two cases where return of form A has been delayed we have indicated what we believe to be the main interests of a participant.

Participants

Professor T W Anderson, Department of Statistics, Sequoia Hall, Stanford University, Stanford, CALIFORNIA 94305, USA
ABDEGH

Professor D J Bartholomew, Department of Statistics and Mathematical Sciences, London School of Economics, Houghton St., LONDON WC2A 2AE, UK
CDEFK

Dr Michael Bartlett, Mathematics Department, North East London Polytechnic, Romford Rd., LONDON E15 4LZ, UK
ADFHI

Dr R A Brown, Department of Mathematical Sciences, The University, DUNDEE DD1 4HN, UK
FH.

Dr N N Chan, Department of Statistics, Science Centre, The Chinese University of Hong Kong, SHATIN, N.T., HONG KONG
ABDHIJ

Professor J B Copas, Department of Statistics, University of Birmingham, P O Box 363, BIRMINGHAM B15 2TT.
ADFGHI

Dr G R Dolby, DMS, CSIRO, Cunningham Laboratory, 306 Carmody Rd., ST LUCIA, QUEENSLAND 4067, AUSTRALIA
ABCDFI

Dr B S Everitt, Biometrics Unit, Institute of Psychiatry, Denmark Hill, LONDON SE5, UK
DEF

Mr P R Fisk, Department of Statistics, University of Edinburgh, King's Buildings, Mayfield Rd., EDINBURGH EH9 3JZ. UK
ABFJ

Professor Wayne A Fuller, Department of Statistics, Iowa State University, Ames, IOWA 50011, USA
ABCDFGHI

Professor L J Gleser, Department of Statistics, Mathematical Sciences Bldg., Purdue University, West Lafayette, INDIANA 47907, USA
ABFHIL

Mr J C Gower, Statistics Department, Rothamsted Experimental Station, HARPENDEN, HERTS AL5 2JQ, UK.
DEFGHI

Dr D Griffiths, DMS, CSIRO, P O Box 218, LINDFIELD, N.S.W. 2070, AUSTRALIA
ABFHIMN

Dr E H Inselmann, Department of the Army, Combined Arms Operations Research Activity, Fort Leavenworth, KANSAS, 66027, USA

Dr A A M Jansen, TNO, Bezoekadres, Staringgebouw, Marijkeweg 11, 6700 AC WAGENINGEN, NETHERLANDS
FH

Professor P Jolicoeur, Department de Sciences biologiques, Universite de Montreal, Case Postale 6128, MONTREAL, QUEBEC H3C 3J7, CANADA
ABDEF

Professor K G Joreskog, Department of Statistics, University of Uppsala, P O Box 513, S-751 20 UPPSALA, SWEDEN.
ADFJ

Professor Naoto Kunitomo, Faculty of Economics, University of Tokyo, Bunkyo-ku, Hongo 7 - 3 - 1, Tokyo 113, JAPAN
J

Dr H Linssen, Technische Hogeschool, Den Dolech 2, P O Box 513, 5600 MB EINDHOVEN, NETHERLANDS
ABCDHI

Professor R P McDonald, School of Education, Macquarie University, North Ryde, NSW 2113, AUSTRALIA
DEF

Professor T K Mak, Department of Statistics, University of Hong Kong, HONG KONG
BDI

Dr Richard Morton, DMS, CSIRO, PO Box 1965, CANBERRA CITY, ACT 2601, AUSTRALIA
ABFH

Dr J E Mosimann, Bldg 12A, Room 3045, DCRT, National Institutes of Health, Bethesda, MARYLAND, 20205, USA.
ABDFP

Dr W M Patefield, Department of Mathematics, University of Salford, SALFORD, M5 4WT, UK
ABDFI

Dr Gavin Ross, Statistics Department, Rothamsted Experimental Station, HARPENDEN, Herts, AL5 2SQ, UK
ABFI

Dr R Sandland, DMS, CSIRO, P O Box 218, LINDFIELD, NSW 2070, AUSTRALIA
ABFGHIPR

Prof. Dr Hans Schneeweiss, Seminar f. Okonometrie u. Statistik, Ludwig Maximilians-Universitat Munchen, Akademiestr 1/1, D-8000 MUNCHEN 40, WEST GERMANY
ABDFHIJS

Dr A Spanos, Department of Economics, Birkbeck College, 7-15 Gresse St., LONDON W1P 1PA, UK
BDFJ

Professor P Sprent, Department of Mathematical Sciences, The University, DUNDEE, DD1 4HN, UK
ACFIMP

Dr C Theobald, Department of Statistics, University of Edinburgh, King's Buildings, Mayfield Rd., EDINBURGH EH9 3JZ
ABCDFGHIT

Dr K M Wolter, Bureau of Census, US Department of Commerce, Washington, DC, 20233, USA.
ABJ

PROGRAMME

<u>Wednesday 24 August</u>
9.00 - 11.00am Registration at Chalmers Hall.
11.15am - 12.30pm Plans and aims for the Workshop. Discussion introduced by P Sprent.

2.00 - 5.00pm Discussion symposium: Robust and distribution free estimators of structural and functional relationships. Organizer: D Griffiths.

<u>Thursday 25 August</u>
9.00 - 10.50am Relations between linear functional relationships, factor analysis and simultaneous equations. T W Anderson.
11.05am - 12.15pm. A linear structural relationship with replicated data and with errors in the equation. H. Schneeweiss.

2.00 - 5.00pm Discussion symposium. Fitting non-linear functional relationships. Organizer: W M Patefield.

<u>Friday 26 August</u>
9.00 - 10.30am Paper by L J Gleser (title to be announced).
10.50am - 12.00noon A model for multinomial response error. W A Fuller.

2.00 - 3.15pm Linear Functional Relationships with correlated and heterogeneous errors. N N Chan.
3.30 - 4.45pm Estimation in Structural relationship models. T K Mak.

<u>Saturday 27 August</u>
No formal activity.

<u>Sunday 28 August</u>
Excursion to Scottish Highlands. (There will be a small charge for this to be collected on registration).

<u>Monday 29 August</u>
9.00 - 10.00am Principal Components, Factor Analysis and multivariate allometry. P Jolicoeur.
10.15 - 11.15am Size and Shape Variables with biological applications. J E Mosimann.
11.15 - 12 noon Fitting Generalized Allometric models to multivariate growth studies.I. D Griffiths.

2.00 - 2.45pm Fitting Generalized Allometric models to multivariate growth studies. II. R Sandland.
2.45 - 5.30pm Discussion symposium. Functional relationships and multivariate gneralizations of allometry. Organizers: D Griffiths and R Sandland.

Tuesday 30 August

9.00 - 10.30am Factor Analysis as an errors in variable model. K G Joreskog.

11.00 - 12noon Foundations of Factor Analysis. D J Bartholomew.

2.00 - 3.30pm Some connections between factor analysis and functional or structural relationships. G R Dolby.

3.45 - 5.00pm Asymptotics with an application to system identification in the presence of input errors. H N Linssen.

Wednesday 31 August

9.00 - 10.15am Estimating equations for functional relationships and related problems. R Morton.

10.30 - 11.45am Likelihood ratio test and confidence regions for the coefficients of linear structural relationships. C M Theobald

Afternoon: No formal activity.

7.00pm Workshop Dinner.

Thursday 1 September

9.00 - 10.10am Some practical applications of functional and structural relationships. J B Copas.

10.25 - 11.25am Linear structural relationships applied to calibration of biochemical assays. M L Bartlett.

11.25am - 12.20pm Some practical problems in establishing functional relationships. A A M Jansen.

Afternoon. No formal activity.

Friday 2 September

9.00 - 10.00am Consistency and asymptotic variances of estimators. W M Patefield.

10.00am onward. Discussion symposium: Consistency and large sample properties of estimators. Organizer: W M Patefield.

Saturday 3 September

No formal activity.

Sunday 4 September

Excursion to an Historic Scottish site.

Monday, 5 September

9.00 - 12.00pm Discussion symposium: Systems of equations in econometrics. Organizer: H Schneeweiss.

Afternoon. No formal activity.

Tuesday 6 September
9.00 - 10.15am. The geometry of errors in variables estimation problems and extensions. A Spanos.
10.30am - 12.00noon. The workshop - what have we achieved? A discussion review introduced by P Sprent.

Afternoon. No formal activity.

OPEN FORUM PROGRAMME

Wednesday 7 September

9.00 - 9.45am Registration.
9.45 - 10.30am Functional relationships and the combination of regression analyses. C. M. Theobald.
11.00am - 12 noon Maximum Likelihood for linear structural relationships. T. W. Anderson.

1.45-2.45pm A general model for linear functional relationships and factor analysis. K G Joreskog.
2.45 - 3.30pm Mixed and random effect models in latent trait analysis. D J Bartholomew.
3.45 - 4.30pm Latent Variable models in econometrics. A Spanos.
4.30 - 5.15pm Large sample properties of estimators of functional relationships. W M Patefield.

Thursday 8 September

9.00 - 9.45am The failure of regression based and other multivariate linear techniques in modelling generalizations of allometry. D Griffiths.
9.45 - 10.30am A functional relationship approach to modelling generalizations to allometry. R Sandland.
10.45 - 11.30am Size and shape analyses. Canonical axes of shape. J E Mosimann and J N Darroch.
11.30am - 12.15pm Estimating linear equations with errors in variables. The merging of two approaches. H Schneeweiss.

1.45 - 2.30pm Catch 22. Fishing for realistic assumptions in the analysis os squid data. G R Dolby.
2.30 - 3.15pm Paper by L J Gleser. Title to be announced.
3.30 - 4.15pm Estimation of polynomial functional relationships. T K Mak.
4.15 - 5.00pm Bootstrapping non-linear functional relationships - a special case. H Linssen.

Friday 9 September

9.00 - 9.45am Shrinkage estimators in linear models. J B Copas
9.45 - 10.30am Estimation for the non-linear functional model. W A Fuller.
10.45 - 11.30am An application of functional relationships to dating metamorphic rocks. R Morton.
11.30am - 12.15pm Multivariate linear functional relationships. A generalized least squares approach. N N Chan.

1.45 - 3.30pm Contributed papers.

Circular D

TO ALL INVITED PARTICIPANTS

WORKSHOP ON FUNCTIONAL AND STRUCTURAL RELATIONSHIPS AND FACTOR ANALYSIS

UNIVERSITY OF DUNDEE

24 August - 9 September 1983

This circular supplements Circular C and contains information current at 12 July 1983. Unless some special situation arises it is not intended that any additional circular will be sent out before the meeting. If you have a query on any matter concerning the workshop that has not been covered by this or previous circulars please do not hesitate to write.

PROGRAMME AMENDMENTS

One or two time changes have had to be made in the draft programme. These are already under discussion with the contributors concerned and will be incorporated in the final programme for the meeting. Additional papers for the workshop which will also appear on the final programme are:

R. P. McDonald: Confirmatory Models for Non-linear Structural Analysis. (Probably Thurs 25 August pm, as part of discussion symposium)

N. Kunitomo: Estimation in Dynamic Linear Functional Relationship Models with Applications in Econometrics. (Probably Mon 5 Sept, 2.00pm.)

An additional Open Forum paper will be given by R. P McDonald under the title "Exploratory and confirmatory non-linear factor analysis". (Time to be notified in final version of programme).

TRAVEL AND ACCOMMODATION

Enclosed with this circular is a statement of what we understand to be your accommodation requirements at Chalmers Hall. In a few cases this statement also contains replies to queries recently made by individuals. For those whose accommodation is being paid wholly from SERC funds we have simply confirmed that we shall make payment direct to the University Authorities. For those who are paying accommodation from their own resources or are only partly covered by SERC funds we indicate an approximate cost. This cost is subject to adjustment depending upon the numbers of meals taken on day of arrival and departure.

Where appropriate we have indicated the cost for spouses based on the information given on your form B. This is also subject to adjustment depending upon the number of meals taken on day of arrival and departure.

In making estimates a deduction of £3.00 has been made for the night of the conference dinner (31 August) since no dinner will be served at Chalmers Hall that evening. As already indicated payments for the Conference Dinner, as well as for excursions and pleasure flights, should be made separately at registration.

Spouses of participants coming to Dundee are also invited to attend the Workshop dinner at the prices indicated in Circular C and payable at registration.

Please note that dinner on nights other than 31 August will normally be available only from 6.00pm-6.30pm. Any exceptions will be announced at the workshop. If you were not able to inform us of your expected time of arrival when you sent in form B it would be helpful if you could send this information as soon as you have it, especially if you will be requiring dinner on the day of your arrival. If your arrival is later than 6.30pm please make your own arrangements for eating on the evening of arrival. We can advise on various restuarants/snack bars, etc., if you arrive after 6.30pm and require nourishment!

Wines and beers will be available for purchase at dinner each evening except 23 August and 9 September for those desiring them. There will not be an evening bar service after dinner but there are a number of pubs in the neighbourhood of both Chalmers Hall and the University.

As already indicated if you can tell us when and where you are arriving in Dundee we shall endeavour to meet your train or plane. Please note that there are now air services London (Heathrow) to Dundee and Manchester to Dundee operated by Air Ecosse. The London service has only recently started and you should check timetables and fares with your travel agent.

SOCIAL ACTIVITIES

By courtesy of the Principal of the University and Mrs Neville a sherry reception for all Workshop and Open Forum Participants and attending spouses will be held at University House from 5.30-6.30pm on Wednesday 7 September. Transport arrangements will be notified at the Workshop.

For the duration of the Workshop informal social activity will be encouraged. If you play a musical instrument and it is sufficiently portable please bring it! We know one participant will be bringing his violin and is keen to form a chamber group. If you have any other talents as an entertainer we hope you will let us enjoy them. If you are a golfer don't forget Dundee is surrounded by courses. Temporary membership is easily available to visitors at several of them at very modest fees.

P Sprent

Department of Mathematical Sciences,
The University,
DUNDEE DD1 4HN,
Scotland,
12 July 1983

FUNCTIONAL AND STRUCTURAL RELATIONS AND FACTOR ANALYSIS

"O P E N F O R U M"

UNIVERSITY OF DUNDEE

Wednesday 7 to Friday 9 September 1983

Joint sponsors:
Research Section of the Royal Statistical Society
The Committee of Professors of Statistics

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The "OPEN FORUM" is associated with an International Research Workshop on the above topics supported by the UK Science and Engineering Research Council (SERC). The Workshop is restricted to invited participants representing a wide cross-section of interests.

The FORUM is open to anyone interested, although accommodation will be limited. The FORUM will consist of three main elements:
Invited Papers. Contributed papers. Seminars

The provisional list of those attending the workshop and who are expected to participate in the FORUM includes
J A Anderson, T W Anderson, V Barnett, Michael Bartlett, D Bartholomew, N N Chan, J B Copas, G Dolby, B Everitt, W Fuller, L J Gleser, D Griffiths, A M Jansen, P Jolicoeur, K Joreskog, H N Linssen, T K Mak, R Morton, J. Mosimann, M Patefield, G Ross, H Schneeweiss, R Sandland, A Spanos, P Sprent, C Theobald.

VENUE
The FORUM will be held at the University of Dundee and accommodation on a full board basis will be available in Chalmers Hall, a centrally situated University Residence, providing accommodation in single or twin bedded rooms.
The Forum will commence at 9.30 a.m. on Wednesday 7 September and conclude not later than 5 p.m. on Friday 9 September.

PROGRAMME
A detailed programme will be sent to registered participants approximately four weeks in advance of the FORUM. Abstracts of contributed papers will be required by 15 June 1983. Details of the form these should take will be sent to those ticking the appropriate box on the application form. Abstracts of Invited and Contributed Papers will be available at the FORUM.

APPLICATIONS
Applications should be on the form below or on a photocopy thereof. Registration fee: £15 for Fellows of RSS or members of the Insititute of Statisticians; others

(PTO)

£18. Late fee £10 for applications received after 1 June 1983. A deposit of £10 must accompany all applications and any balance due must be received by 15 August 1983. Accommodation will be allocated strictly in order of receipt of applications. If all accommodation is fully booked when an application is received the option of attending the FORUM but arranging accommodation privately will be offered. If this option is not acceptable all money will be refunded. Otherwise the deposit of £10 is non-refundable for cancellations before 15 August; for cancellations after 15 August any refund allowed will be subject to additional deductions to cover expenses already incurred by the organisers. Overseas applicants are requested to forward payments by sterling draft on a UK bank at their own expense.

OPEN FORUM ON FUNCTIONAL AND STRUCTURAL RELATIONS AND FACTOR ANALYSIS

University of Dundee, 7 - 9 September 1983

To Professor P Sprent, Department of Mathematical Sciences, The University, Dundee, DD1 4HN, Scotland.

I wish to attend the OPEN FORUM. I require accommodation at Chalmers Hall as indicated below.* I enclose a cheque Payable to "The University of Dundee" for £__________ being for full cost/or deposit* (£10 non-refundable). Any balance is due by 15 August.

Late Application fee (after 1 June) £10....£__________

Registration Fee (RSS/IOS £15, others £18).£__________

Board and Accommodation:-

Tues 6 Sept. Dinner/Bed/Breakfast £11.20...£__________

Wed 7 Sept. Full Board £14.30..............£__________

Thurs 8 Sept. Full Board £14.30............£__________

Fri 9 Sept. Lunch £2.50, Dinner £3.00.....£__________

TOTAL £__________

BLOCK CAPITALS PLEASE

NAME (Prof/Dr/Mr/Mrs/Miss/Ms/etc)______________________________

ADDRESS____

____

____

I prefer a single/twin room*. (If you wish to share a twin room with a colleague who is also attending please indicate his/her* name:____)

*Delete as appropriate.

Please tick here if you wish to submit a contributed paper ☐

Signature________________________________ Date______________